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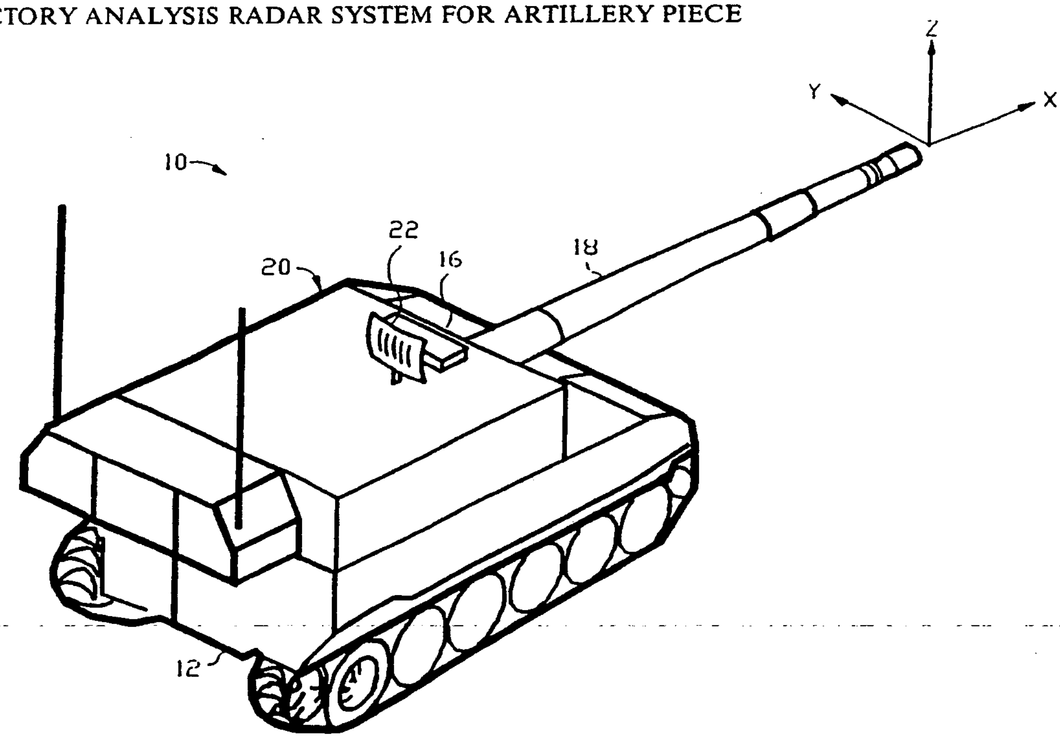
(54) Title: TRAJECTORY ANALYSIS RADAR SYSTEM FOR ARTILLERY PIECE



(57) Abstract

A low cost easily deployed, yet highly accurate weapon mounted trajectory analysis radar system uses optimized Doppler radar signals to detect the actual trajectory of a projectile fired from an artillery piece such as a 155 mm Howitzer (10). The actual trajectory data is used to determine an atmospheric model that may be used to aim the weapon for future firings. The system includes a Doppler radar system (16) having a turret mounted antenna (22) that tracks the projectile, a digital signal processor (30) using an FFT to convert radar pulses to trajectory data and a data processing system (32) that analyzes the trajectory data to develop a true atmospheric model.

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TRAJECTORY ANALYSIS RADAR SYSTEM FOR ARTILLERY PIECE

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Background of the Invention

As weapons systems have developed, there have been substantial increases in both range and accuracy. However, systems that provide the greatest accuracy are extremely expensive, cumbersome to deploy and subject to failure because of their complexity. A need thus arises for a comparatively inexpensive weapons system that is reliable and accurate, yet lightweight and easy to use and deploy.

The trajectory of motion and hence the impact point of a nonguided projectile fired from an artillery piece such as a 155mm Howitzer is determined by a relatively small number of parameters that are fairly well understood. These include the projectile shape, gun barrel characteristics, initial velocity of the projectile and atmospheric conditions. Typically all of these parameters will vary slowly over time, but if they can be determined accurately from one firing they will remain reasonably stable for a second firing shortly thereafter.

For example, the gun barrel typically contains helical grooves or rifling that causes the projectile to spin and attain greater stability and predictability as it exits that gun barrel. As the grooves wear, the impact on the projectile will change and the flight characteristics will gradually change with time.

Similarly, the exact initial muzzle velocity will change gradually with barrel characteristics, with temperature and with the powder charge that is used. The powder charge will be quite consistent within a manufacturing batch so that the initial muzzle velocities for two consecutive firings will be nearly the same. Atmospheric conditions including air density and wind velocity at different altitudes will tend to vary more rapidly than some of the other parameters. However, even atmospheric conditions will usually remain reasonably stable for many minutes at a time.

Radar systems have been developed to improve the accuracy of projectile firings. These systems tend to follow one of two configurations. One is a muzzle velocity radar system (MVR) that accurately determines the initial muzzle velocity. The other is a trajectory measurement radar system that tracks the trajectory of the projectile from firing to impact.

The muzzle velocity radar system is compact, lightweight and relatively inexpensive. However, it only provides accurate information as to one of the many parameters that determine the final impact point, namely initial muzzle velocity. This information significantly improves the accuracy of a firing, but leaves many important parameters to be approximated by other means. Examples of this type of system can be found in U.S. patent 4,837,718 to Alon and U.S. patent 3,918,061 to Elgaard.

The trajectory measurement radar systems use tracking radar systems with multiple sensor points located some distance from a weapon. These systems are large, complex and difficult to properly deploy, especially under battle conditions where time may be critical. Because of the complexity of these systems and the distances over which they must be deployed, their reliability is questionable. The high power radar signals that track the small projectiles from a substantial distance are subject to detection and tracking by enemy forces. However, because these systems track the complete trajectory of a projectile, they can be used to compile extremely accurate estimations of all of the parameters that affect the accuracy and final impact point of a projectile fired from a gun.

U.S. patent 4,679,748 to Blomqvist et al. discloses a system that monitors the trajectory of a guidable projectile. The projectile has flight control surfaces that are controlled in response to actual tracking information to guide the projectile to a desired impact point. The antenna is located off axis from the trajectory to provide the required trajectory information.

Summary of the Invention

A relatively inexpensive, lightweight trajectory analysis radar system for an artillery piece in accordance with the invention includes a gun mounted radar antenna tracking the trajectory of a projectile, a radar system sending radar pulses to and receiving radar reflections from the antenna, a signal processor analyzing the radar reflection signals to produce a representation of the projectile trajectory at least to the peak of the trajectory and a data processing system analyzing the trajectory data to determine initial muzzle velocity and atmospheric data. This data can then be output to a fire control computer system to enable the impact point for a next firing to be more accurately predicted.

An advantageous trajectory analysis algorithm operates in a feedback loop using piecewise linear representation of an atmospheric model in selected elevation increments. The model is used to calculate a trajectory that is compared to the actual trajectory. Errors between the calculated and actual trajectory are used to update the atmospheric model for a next calculation iteration.

Test simulation results suggest that two iterations will typically produce an atmospheric model that represents actual atmospheric conditions with sufficient accuracy. Atmospheric conditions may be assumed with adequate accuracy to be the same for both the rising and falling portion of the trajectory. Analysis of only the first half trajectory from firing to the peak is therefore all that is necessary to create an adequate atmospheric model.

The predictable and relatively constant projectile physical and flight characteristics enable the radar system to be optimized with respect to size and power requirements, while minimizing the possibility of the tracking radar signals being detected by enemy radar units and used to determine the location of a weapon.

For example, mounting of the radar antenna on a recoilless portion of a gun turret with an approximate line of site along the gun barrel assures that the antenna will face the relatively large radar cross section of the trailing end of a projectile. The expected flight trajectory can be used to adjust radar power in accordance with increasing distance from the antenna and the phasing of transmitted pulses can be selected to prevent reflected pulses from interfering with transmitted pulses as the distance of the projectile from the antenna changes. Any required elevation control over the antenna can be limited and easily predicted in advance, while azimuth control may or may not be necessary, depending upon the requirements of any given application. The predictable velocity and position of the projectile can be used to eliminate the detection of false targets and thus improve the accuracy of the radar flight trajectory data.

Brief Description of the Drawings

A better understanding of the invention may be had from a consideration of the following Detailed Description, taken in conjunction with the accompanying drawings in which:

Fig. 1 is a perspective view of an artillery piece having a trajectory analysis radar system in accordance with the invention;

Fig. 2 is a block diagram representation of a trajectory analysis radar system for a weapons system in accordance with the invention;

Fig. 3 is a flow chart illustrating a computer program for analyzing trajectory data to derive atmospheric data in accordance with the invention; and

Fig. 4 is a block diagram illustration of a method of analyzing projectile trajectory data in accordance with the invention.

Detailed Description of the Invention

Referring now to Fig. 1, a weapons system 10 in accordance with the invention includes an artillery piece in the form of a 155mm Howitzer 12 having a track transport system 14 supporting a recoilless gun turret 16 having a recoiling, rifled gun barrel 18 mounted thereon. Mounted on the artillery piece 12 is a trajectory analysis radar system 20 having shown in Fig. 1 only an antenna 22.

Antenna 22 is used to both transmit and receive radar frequency pulses for tracking a projectile that is fired from the barrel 18. Antenna 22 is preferably mounted on a recoilless portion of turret 16 and directed approximately along the line of sight of barrel 18. Conventional azimuth and elevation motion controls are provided for antenna 22, which may be constructed to transmit a narrow angle beam that tracks a reasonably predictable trajectory of a fired projectile. If the beam width is sufficient to assure tracking of a projectile through all atmospheric conditions, it may be possible to eliminate azimuth motion control for antenna 22 in some circumstances.

As a first shot is fired, the radar system 20 tracks the projectile after it exits barrel 18 until it reaches the apex point of its trajectory. Tracking beyond the apex point is possible, but the information gathered tends to be redundant. At the same time, the radar power must be increased as the distance of the projectile from the antenna 22 increases. The increased operating time and the increased power would significantly increase the probability of enemy detection without significantly increasing the accuracy of future rounds.

Enemy detection can be further minimized by having one weapon 10 fire a test round and then communicating the collected meteorological data to other units via secure radio transmissions either directly or indirectly through a fire control center.

Once data has been collected for one or two test rounds, further tracking would typically be discontinued until a significant change in the azimuth or peak elevation of the trajectory occurs or a significant period of time passes that might suggest a change in meteorological conditions along a contemplated trajectory. Even when full tracking is not used, the radar system 20 would typically be operated under low power for a short time of typically less than one second to develop muzzle velocity information for each round. As each round is fired, the latest data for initial muzzle velocity for the same type of ammunition is used to predict muzzle velocity for the next round.

Referring now to Fig. 2, the trajectory analysis radar system 20 includes a digital signal processor 30 which converts radar data to a numeric coordinate data format based upon the center line of the transmitted radar signal, a fire control data processor system 32 and a doppler effect radar system 34. A main system data bus 40 couples data processor system 32 to various functional units within the radar system 34 as well as to general fire control functions of weapons system 10 as represented by fire control operations 36. These fire control operations would typically include elevation and azimuth positioning of turret 16 and barrel 18 of weapons system 10. Data processor system 32 is also coupled by a communication data bus 42 to digital signal processor 30 and to a data output communication channel 44 which might, for example, connect to a secure digital radio transmitter/receiver.

In preparation for firing an initial round, fire control data processor system 32 calculates an appropriate trajectory using the best available meteorological and initial muzzle velocity data and commands fire control operations 36 to position barrel 18 in accordance with the calculated data. The initial round can be either a first attempt at an effective round on target or a purely test

round that is fired at a high elevational angle in the direction of the target. A high elevation purely test round would have the advantage of providing meteorological data over a maximum altitude range and would be exploded shortly after reaching the apex of the trajectory. The highly accurate meteorological data derived from the test round could then be utilized to calculate with high accuracy the required trajectory for an effective round on target.

In either event, the barrel 18 is positioned and a round is fired. An accelerometer 50 or similar device such as an acoustic wave detector detects the firing of the weapon system 10 and generates in response thereto a firing signal which is communicated to fire control data processor system 32 to establish time zero with respect to the firing of the round.

As soon as the firing of a round is detected, data processor system 32 commands frequency synthesizer 52 and transmitter unit 54 within radar unit 34 to become operational and begin transmitting radar pulse signals through a circulator 56 to antenna unit 22. Initially the projectile will be quite close to the antenna 22 and both the transmitted power and pulse width of the radar signals can be relatively low. As the distance of the projectile from the antenna 22 increases, the transmitted power and transmitted pulse width can both be increased to maintain adequate signal to noise ratios in the energy pulses reflected from the projectile back to the antenna for receipt thereby. In addition, as the projectile follows its normal trajectory, the phase and repetition rate of the transmitted radar pulses can be varied to assure that the reflected radar signals are received at a time window between transmitted radar pulses and to assure that a current pulse is not being transmitted at the same time that a reflection from a previously transmitted pulse is being received.

In a preferred embodiment, the radar pulses have a frequency in the 16-17 GigaHertz range with a pulse width of 0.5-2.0 microseconds. A pulse repetition frequency of 50-100 kHz results in a new pulse being produced every 10 to 20 microseconds. The initial power may be as low as 1 watt and is increased to as much as 200 watts as the projectile reaches its apex. The antenna preferably has a gain of about 39 dB with an elevation beam width of approximately 1.70 degrees and an azimuth beam width of approximately 1.70 degrees. It will be appreciated that other suitable frequencies and parameters could be used as well and can be optimized for any given situation.

As the weapon 10 is fired the firing of the charge creates an initial ionization zone around the barrel 18. During this initial ionization period, the transmitter unit 54 goes through a warmup period and reaches the full commanded power and the digital signal processor 30 ignores any return signals. After approximately 100 milliseconds this initial ionization dissipates and data processor system 32 issues a command over bus 42 to cause digital signal processor 30 to begin receiving and analyzing reflected radar signal data.

The reflected radar signals received by antenna unit 22 include an azimuth difference signal, DIF A, an elevation difference signal, DIF E, and a sum signal. The DIF A and DIF E signals are communicated directly to an RF receiver 60, while the sum signal is communicated through circulator 50 to RF receiver 60. Receiver 60 mixes the three signals with a local oscillator signal from frequency synthesizer 52 with the resultant signals being communicated at an intermediate frequency of approximately 500 kHz to an intermediate frequency receiver 62 for further amplification. IF receiver 62 mixes the signals with a coherent oscillator signal from frequency synthesizer 52 to obtain conventional velocity dependent Doppler signals and communicates the three signals to an

analog to digital converter at the input of digital signal processor 30.

The azimuth and elevation difference signals provide indications of position error of the projectile from the center of line of sight of antenna unit 22. This information is in turn utilized during the course of flight of the projectile to command antenna position control 64 to reposition antenna 22 so as to maintain the projectile near the center of its line of sight. Antenna position control 64 may in turn provide back to data processing system 32 current actual antenna position data which can be combined with relative position data received from DSP 30 over bus 42 to permit calculation of the actual trajectory of the projectile relative to the outer tip of barrel 18.

Digital signal processor 30 processes signal SUM with a 1000-2000 point fast Fourier transform (FFT) to obtain velocity data from the doppler information of signal SUM. In addition, the time of occurrence of each reflection after transmission of the radar pulse signal corresponding thereto and the strength of the received reflected signal relative to the transmitted energy are utilized by digital signal processor 30 to generate range information that is converted to position information in an XYZ coordinate system utilizing the muzzle tip of barrel 18 as the origin.

The three dimensional position and velocity data are calculated by digital signal processor 30 in response to the transmitted pulse repetition rate of approximately 50-100 kHz. This high frequency data is smoothed by digital signal processor 30 with any data points being completed by interpolation of data on either side thereof and utilized to generate data points at a much lower frequency of approximately 100 Hz which are communicated to data processor system 32. Data processor 32 stores these data points for later trajectory analysis and also utilizes the data points on a real time basis to control

the positioning of antenna 20 through antenna position control 64, to control the power of the transmitted radar signals, and to control the pulse repetition rate and pulse duration of the transmitted radar signals so as to optimize the efficiency of radar unit 34. As is conventional, digital signal processor 42 communicates to data processor system 32 sampled data point information at a rate of approximately 100 times per second. The data for each sampled data point for the observed trajectory includes three dimensional velocity data, three dimensional position data, and a probability value indicating the probability that the communicated data point falls within a selected range of accuracy. Information concerning the approximate and expected position and velocity of the projectile can be utilized by digital signal processor 30 to eliminate erroneous, noise induced false detections of projectile position or velocity to improve the probability and effectiveness of detecting true position and velocity.

If the data processor system 32 is fast enough to keep up with communication and antenna positioning requirements and still have additional processing time, it may immediately begin analyzing the trajectory data received from digital signal processor 30 to determine initial muzzle velocity and accurate meteorological data. However, more typically, the data processor system 32 is an Intel 80386 based microprocessor system that does not have sufficient speed and capacity to do both functions simultaneously. Furthermore, it is sufficient that the analysis data be available within a few tens of seconds after the projectile reaches its apex and there is no need for simultaneous computation of both antenna positioning control and trajectory analysis.

The first 32 valid data points that are detected after firing are used to compute projectile muzzle velocity by performing a least squares error fit of the 32 data points to a straight line. Since the initial 32 data

points will commence about 100 milliseconds after firing, the straight line is then used to extrapolate the velocity from the 32 data points back to firing time zero to establish the initial muzzle velocity. This value is stored and utilized to calculate the desired trajectory for the next round. Typically the muzzle velocity will be determined for each round and used to update information for the next round, even when a full half trajectory is not being tracked.

The trajectory data, sampled at 10 millisecond intervals, is then analyzed to establish the meteorological data including X and Y component wind velocity and air density at a plurality of different elevation points in the vicinity of weapon system 10. Meteorological data is typically calculated for sample points at 1000 foot elevation intervals. Polynomial approximation and moving average techniques are used to smooth the meteorological data resulting from the trajectory analysis and linear interpolation is utilized to estimate meteorological conditions between the meteorological sample data points which are stored for the different sample elevation points. In the coordinate system used herein X indicates a down range direction, Y indicates a cross range direction and Z indicates elevation.

An algorithm for collecting the radar data and generating updated meteorological data is illustrated in accordance with the invention in Fig. 3, to which reference is now made. At steps 80 and 82 the actual projectile flight radar measurements are received and conventionally processed by digital signal processor 30 in real time during the actual flight of the projectile.

At step 80 the digital signal processor 30 analyzes the received radar data to produce sample points containing range, range rate, azimuth angle, elevation angle and probability of detection at a rate of 100 points per second. The data is determined relative to the center

line of the radar beam. Data processor system 32 keeps track of antenna position data received from position control 64 and later adds any offsets that result from motion of antenna 22. The data processor system 32 then continues to preprocess the converted data by selecting points having a probability of detection less than a certain threshold and replacing these points with estimated data derived from curve fitting a polynomial line through valid points on either side of the missing points. The completed data is then prefiltered using integration and moving average techniques to smooth out any radar induced noise from the sample data points. The three dimensional position and velocity information for the actual projectile trajectory is then used to derive accurate atmospheric information by in effect determining what wind and air density conditions would have caused the detected trajectory.

Once the projectile has reached the apex of its trajectory, the fire control data processor 32 is freed of its real time control functions and begins processing the stored actual trajectory data at step 84. The trajectory analysis proceeds at step 84 by establishing initial values for an atmospheric model or profile at selected small elevation intervals with respect to air density, ρ, cross range wind velocity V_y, and down range wind velocity V_x. The initial atmospheric profile is desirably made as accurate as possible and may be derived from any one of a variety of techniques. For example, conditions can be determined at ground zero and then initially it can be assumed that the ground zero conditions exist at each data point elevation level. Alternatively, the data derived from the last test firing can be utilized as the initial data. Another technique for initializing the atmospheric data may be to receive test fire determined data from a neighboring weapon system, from a fire control center or from other atmospheric data sources.

A closed loop iterative process to generate more accurate atmospheric data is then begun at step 86 by deriving a calculated trajectory for the fired projectile using the initial muzzle velocity determined from the radar measured actual trajectory of the projectile and the initial atmospheric profile X_0. The calculated trajectory produces position and velocity data at 0.01 second intervals corresponding to the 0.01 second data point intervals at which actual trajectory data is produced from the digital signal processor 30 processing of received radar data. At each of the corresponding data points, both position and velocity error for each of the three axial directions are calculated and this data is utilized to generate atmospheric error values for density, cross wind and down range wind at an altitude corresponding to the data point.

Each of the six error parameters ΔX, ΔY, ΔZ, ΔV_x, ΔV_y, and ΔV_z is passed through α digital filter having the form

$$(K/(1 + \tau\alpha s))\Delta\alpha \tag{1}$$

where K is a gain parameter, τ is a time constant, α is the current value of the parameter being filtered, $\Delta\alpha$ is the error value of the parameter being filtered and s is the LaPlace operator. In a preferred implementation of the invention, K and τ have the values shown in TABLE I:

	K		τ
ΔX	0.05	(m/s)/m	0.1 sec.
ΔV_x	10.00	(m/s)/(m/s)	2.0 sec.
ΔY	0.05	(m/s)/m	0.1 sec.
ΔV_y	10.00	(m/s)/(m/s)	2.0 sec.
ΔZ	0.01	(kg/m^3)/m	0.1 sec.
ΔV_z	0.20	(kg/m^3)/(m/s)	1.0 sec.

TABLE I: Filter Parameter Values

Still within step 86 the two filtered X direction error values for position and velocity, ΔXF and ΔVXF, are added to obtain a down range wind velocity error value ΔVWX. The two filtered Y direction error values for position and velocity, ΔYF and ΔVYF, are added to obtain a cross range wind velocity error value ΔVWY and the two filtered vertical error values for position and velocity, ΔZF and ΔVZF, are added to obtain an air density error value $\Delta\rho$.

These atmospheric model error values are then used at step 88 to update the current atmospheric model. During the first pass or iteration through loop 96, the current model is the starting model. The algorithm for updating the current atmospheric model adds the error values to the values of the current atmospheric model. Typically the negative error feedback would be a subtraction, but it will be apparent that whether one adds or subtracts is merely a matter of the sign used for the error values. Those skilled in the art can use the proper combination of sign changes and addition or subtraction to implement a negative feedback loop and cause the atmospheric data model to converge toward the true atmospheric conditions.

At the end of a test firing sequence represented by get radar measurements 80 in Fig. 3, the data processor system 32 has received and stored data from DSP 30 at 10 millisecond intervals defining the following parameters for the ballistic projectile:

range
range rate
azimuth angle
elevation angle
probability of detection

The data begins with the capture of valid data following the initial ionization interval and continues to at least the top of the ballistic trajectory curve.

The initial data format received from the DSP 30 is then converted to three dimensional 6 degrees of freedom position and velocity format that places the origin at the projectile and produces for each 10 millisecond sampled data point a set of position and velocity values relative to the firing point. The data produced is:

P_x position (down range)
P_y position (cross range)
P_z position (elevation)
V_x velocity (down range)
V_y velocity (cross range)
V_z velocity (elevation)

This transformed data is computed from the original data for the corresponding sampled data points together with any offsets that occur as a result of positioning of antenna 22 during the course of the trajectory. Relative antenna 22 position for each of the data points is received from antenna position control 64 and stored by data processor system 32 in such a way that the antenna 22 position data can be correlated at this time with the radar analysis 10 millisecond sampled data point data. If antenna 22 is mounted on a turret of transport system 14, then any turret motion must be similarly considered. Using ordinary geometric relationships the position and velocity data can be calculated as follows:

$$P_x = R \cdot \cos(E\ell) \cdot \cos(Az) \quad (1)$$

$$P_y = R \cdot \cos(E\ell) \cdot \sin(Az) \quad (2)$$

$$P_z = R \cdot \sin(E\ell) \quad (3)$$

$$V_x = \dot{R} \cdot \cos(E\ell) \cdot \cos(Az) - R \cdot \dot{E\ell} \cdot \sin(E\ell) \cdot \cos(Az) - R \cdot \dot{Az} \cdot \cos(E\ell) \cdot \sin(Az) \quad (4)$$

$$V_y = \dot{R} \cdot \cos(E\ell) \cdot \sin(Az) - R \cdot \dot{E\ell} \cdot \sin(E\ell) \cdot \sin(Az) + R \cdot \dot{Az} \cdot \cos(E\ell) \cdot \cos(Az) \quad (5)$$

$$V_z = \dot{R} \cdot \sin(E\ell) + R \cdot E\ell \cdot \cos(E\ell) \quad (6)$$

where R denotes range, $\dot{R}$ denotes range rate, $E\ell$ elevation angle, $\dot{E\ell}$ elevation angle rate, Az azimuth angle, and $\dot{Az}$ azimuth angle rate. The angular rates, $\dot{E\ell}$ and $\dot{Az}$, are computued as the difference of a new measurement data point and the previous data point divided by the sampling time of 10 milliseconds.

As the position and velocity data is calculated from the radar responses, a probability of detection value is determined from the signal to noise ratio of the reflected radar signal as calculated by isp 30. If the signal to noise ratio is less than or equal to 4 dB, the probability of detection is assigned a value of zero. For a s-n ratio greater than 4 dB and less than or equal to 6 dB, the value is 0.1. If greater than 6 dB but less than or equal to 8 dB, the value is 0.3. If greater than 8 dB but less than or equal to 10 dB, the value is 0.65. If greater than 10 dB but less than or equal to 12 dB, the value is 0.85. If greater than 12 dB but less than or equal to 14 dB, the value is 0.99. If the signal to noise ratio is greater than 14 dB, a value of 0.99 is assigned to the probability of detection.

As data for a sample point is processed, a random number is generated to create an event having a probability of occurrence equal to the probability of detection. For example, a random number between 0 and 1 is generated and compared to the probability of detection. If the random number is less than or equal to the probability of detection, the event is deemed to have occurred and the corresponding sample data point is treated as valid. If the probability event does not occur, the sample data point is discarded and the missing point is determined from other points, either by a curve fit algorithm or by interpolation. A conventional least square curve fit of a polynomial to several points surrounding the missing point is preferred. In this way data at sampled points is used on a statistical basis in proportion to the probability that the data represents a valid trajectory point.

An automatic weighing function is thus established where the data defining the sampled trajectory is weighed in favor of points having a higher probability of detection. However, points having a lower probability of detection are not completely ignored.

Once three dimensional position and velocity sample data points have been calculated for each 10 millisecond interval, the 6 sets of data are each independently smoothed by a suitable filtering technique such as use of integration or a moving average. The resulting smoothed data thus represents the actual, measured trajectory of the projectile at 10 millisecond intervals. This completes the processing of the actual trajectory data at step 82 in Fig. 3.

At step 84 an initial estimate of the atmospheric model is established. The closer the initial estimate is to the true actual atmospheric conditions, the faster the determined atmospheric model will converge to the actual atmospheric conditions in response to processing using the actual trajectory data. One

technique is to initially assume that ground conditions exist at all elevations of interest. Alternatively, the initial estimate can be derived from a previous firing at the same or a neighboring location, from weather reports or forecasts, from observations or simply from a pre-established arbitrary estimate such as a typical air density profile and zero wind velocity.

The initial atmospheric data is established for air density; down range or X wind velocity VWX^0 and cross range or Y wind velocity VWY^0. Temperature , T degrees, at the firing point is also established to enable future adjustment of air density and ballistic weapon parameters in response to temperature. However, the temperature is assumed to be correct and is not modified in response to the actual trajectory data. The atmospheric values are stored in a table in small elevation increments beginning with the firing point as elevation, Z, equals zero. Typically data is stored at an elevation corresponding to each sample data point along the projectile trajectory and interpolation is used to find atmospheric data at elevations between these sample data points. Data could alternatively be stored for fixed elevation increments. Increments of no more than 1000 feet are preferred.

Linear interpolation is used to obtain atmospheric parameters at elevations between the stored elevation points. A more sophisticated interpolation or curve fitting could be used if desired, but linear interpolation is convenient and is sufficiently accurate to produce good results.

In the present model the atmospheric conditions vary only with altitude and for a given altitude are assumed constant and uniform throughout the range of the weapons system 10.

The method of starting with an initial estimate of an atmospheric model and causing the model to converge toward an accurate true atmospheric model is analogous to a digital position feedback servo system as illustrated in Fig. 4. The converging process can be more clearly understood by examining the same process from two different perspectives as illustrated in Figs. 3 and 4.

Fig. 4 represents a computer simulation of a method in accordance with the invention of developing an atmospheric model in the vicinity of a weapons system 10. At block 102 a current, accurate true atmospheric model of temperature, air density, down range wind velocity and cross range wind velocity is assumed.

At step 104 the projectile equations of motion are used to calculate a simulated actual trajectory that would occur given the true atmospheric model assumed at step 102. A 6 degree of freedom (DOF) mathematical model has been developed for all major weapons systems including the 155mm Howitzer weapons system which is representative of the weapons system 10. This model permits the assumption of any initial condition such as temperature, muzzle velocity, azimuth angle, elevation angle, projectile spin rate for each different aerodynamic projectile shape or other physical characteristics. The model is conventionally applied to an atmospheric model to calculate a projectile trajectory. One well known model is the BRL aerodynamic model from the Ballistic Research Laboratory at the Aberdeen Proving Grounds.

In any event, at step 104 the selected projectile model is applied to the atmospheric model established at step 102 to generate simulated sample data points at 10 millisecond intervals representing in three dimensions the position and velocity of a fired projectile such as a 155mm projectile.

Subsequently at step 106 the position velocity data of step 102, 104 is converted to a radar representation format and a radar model is applied to the calculated trajectory to superimpose simulated radar noise and probability of detection information. Some of the probability information is below the detection threshold, necessitating the estimation of missing points from surrounding data, just as would occur in the generation of true radar analysis data. Steps 102, 104 and 106 of Fig. 4 thus correspond to step 80 in Fig. 3.

At steps 108 and 110 the radar simulated trajectory data is converted to a position, velocity format and smoothed by a prefilter step 110. The resulting data is a set of simulated dated points at 10 millisecond intervals that simulates the output from process measurements step 82 of Fig. 3.

An initial estimate of an atmospheric model is then established at step 84 in Fig. 3 and at a corresponding step 112 in Fig. 4. These initial values are used to initialize a current model data set at step 114 of Fig. 4. The initialized current atmospheric model from step 84 of Fig. 3 is applied to a loop 96 and similarly the current atmospheric model from step 114 of Fig. 4 is applied to a loop 116 that corresponds to loop 96 of Fig. 3.

The loops 96 and 116 are functionally identical and operate on the current atmospheric model to cause the values represented thereby to converge toward the true correct atmospheric model represented by true atmospheric conditions in Fig. 3 and by atmospheric conditions simulated at step 102 of Fig. 4.

At step 86 of Fig. 3 an aerodynamic model of the projectile is applied to the current estimate of the atmospheric model to calculate a ballistic trajectory. The calculated ballistic trajectory is then compared with the true trajectory data developed at step 82 and the position and velocity difference or error information can be used to calculate error values for the current atmospheric model. The error data added to the current atmospheric model values at step 88 to form a new, rough atmospheric model. The new, rough atmospheric model is smoothed at step 90 and transferred to form a new current atmospheric model at step 92.

At step 94 of Fig. 3, an exit criterion is tested. In the present instance it is determined that loop 96 has experienced only one iteration and control returns to step 86 to execute a new iteration with the smoothed new atmospheric model from steps 90 and 92 being used as the current atmospheric model.

When the exit criteria is met at step 94, the loop 96 is exited and the then existing current atmospheric model becomes the assumed actual atmospheric model to be used in aiming calculations for subsequent firings of weapons system 10 and neighboring weapons systems.

The loop 116 of Fig. 4 is functionally identical to loop 96 of Fig. 3 and begins at step 120 with the application of a projectile model to the current atmospheric model from step 114. Step 120 is identical to step 104 except that a different atmospheric model is used to calculate the trajectory. The trajectory from step 120 is subtracted from the calculated true trajectory at subtraction step 122 to produce trajectory error values that are applied to a transformation and smoothing step 124 that generates atmospheric model error values ΔVWX, ΔVWY and $\Delta \rho$.

The transforming and smoothing function 124 uses the equivalent of position plus velocity feedback to filter and sum the trajectory error values to produce the atmospheric model error values. Although not explicitly shown, it will be understood that the atmospheric error values are determined for the elevations computed by block 120 at 10 millisecond intervals.

Transformation step 124 applies to each of the 6 trajectory error positions and velocity error values a low pass filter function 130-135 represented in LaPlace notation by

$$E^* = (K^*/(1 + \tau^* s))\Delta^* \qquad (7)$$

where E* is one of the 6 trajectory error values, K* is a scaling or weighting value, τ is a time constant and s is the LaPlace operator.

An adder 136 sums the weighted and low pass filtered X position and velocity trajectory error values to produce an X component wind velocity error value ΔVWX. An adder 138 sums the weighted and low pass filtered Y position and velocity trajectory error values to produce a Y component wind velocity error value ΔVWY. An adder 140 sums the weighted and low pass filtered Z position and velocity trajectory error value to produce an air density error value $\Delta\rho$. Subtracter 122 and transformer 124 thus correspond to step 86 of Fig. 3.

These filter equations are set forth below using the weighting values and time constants set forth in TABLE I.

$$\Delta VWX = \Delta XF + \Delta VXF \qquad (8)$$

$$\Delta VWY = \Delta YF + \Delta VYF \qquad (9)$$

$$\Delta\rho = \Delta ZF + \Delta VZF \qquad (10)$$

where,

$$\Delta XF = (0.05/(1 + 0.1x\ s))\Delta x \quad (11)$$

$$\Delta VXF = (10/(1 + 2V_x\ s))\Delta V_x \quad (12)$$

$$\Delta YF = (0.05/(1 + 0.1y\ s))\Delta y \quad (13)$$

$$\Delta VYF = (10/(1 + 2V_y\ s))\Delta V_y \quad (14)$$

$$\Delta ZF = (0.01/(1 + 0.1z\ s))\Delta z \quad (15)$$

$$\Delta VZF = (0.2/(1 + 1V_z\ s))\Delta V_z \quad (16)$$

An adder step 142 corresponds to step 88 of Fig. 3 to add the atmospheric error data to the current atmospheric data to produce new atmospheric data that is smoothed at step 144 and applied to the current atmospheric model at step 114 to replace the original current data with the new, smoothed atmospheric data. An exit substep 150 is then performed within step 114 to test for exit conditions. Upon exiting, the current atmospheric data of step 114 becomes the data used for aiming calculations for weapons system 10.

It will be noted that the adder 142 of Fig. 4 corresponds to the update step 88 of Fig. 3, that smoothing step 144 of Fig. 4 corresponds to smoothing step 90 of Fig. 3 and that transfer of the new atmospheric model to the current atmospheric model at step 114 of Fig. 4 corresponds to step 92 of Fig. 3. Test 150 of Fig. 4 corresponds to exit test 94 of Fig. 3.

In computer simulations of the present invention, it was found that two iterations of loops 96, 116 were sufficient to cause the current atmospheric model to adequately represent the true atmospheric model. A greater or lesser number of iterations could of course be used as the exit criteria. Alternatively, exiting could

be based on the magnitudes of the trajectory or atmospheric error values; i.e., when these values drop below a selected threshold.

A trajectory analysis radar system simulation program written in the Fortran programming language using the ACSL (Advanced Continuous Simulation Language) to the implement the projectile equations of motion 120 and the low pass filter function 124 is set forth in APPENDIX A hereto.

While particular arrangements of a trajectory analysis radar system have been shown and described for the purpose of enabling a person of ordinary skill in the art to make and use the invention, it will be appreciated that the invention is not limited thereto. Accordingly, any modifications, variation or equivalent arrangements within the scope of the attached claims should be considered to be within the scope of the invention.

APPENDIX A

oooooooooo LEAR ASTRONICS CORP. oooooooo
ENGINEERING
PRINTED ON TALARIS 1590/LASER PRINTER

USER NAME = ARMAL

```
**********************************************************************
FILE NAME - ANALYSIS:[ARMAL.TAR]TAR18.MEM;1
**********************************************************************
```

PRINTED FROM NODE - VAX2

AT TIME = 16-OCT-1990 15:07:03.81

FILE CREATION DATE - 16-OCT-1990 15:05:26.96

LAST REVISION DATE - 16-OCT-1990 15:06:09.19

BLOCK SIZE OF FILE - 341

File: RADAR_COM18.FOR

```
C*************************************************************************
C
C INCLUDE FILE FOR RADAR COMPUTATIONS                         02-MAY-1990
C name: RADAR_COM18.FOR
C
C*************************************************************************

  IMPLICIT NONE

  INTEGER ISEED/2234567/

C------ Radar parameter definitions and units

  ! The dB unit of X is defined as 10*LOG10(X)

  ! Variables set by user via routine RADARSET                  Units:
  ! ----------------------------------------                    -----
  ! RADAR_POWER     : radar power                               W
  ! ANTENNA_GAIN    : antenna gain                              dB
  ! WAVE_LENGTH     : wave length                               m
  ! RECEIVER_FREQ   : receiver frequency                        Hz
  ! NOISE_FIGURE    : system noise figure                       dB
  ! TOTAL_LOSSES    : system losses                             dB
  ! FFT_LENGTH      : fft length used                           n/a
  ! WEATHER         : clear (0) or 4 mm/Hr rain (1)             0/1

  ! Variables coming from the ACSL portion
  ! ----------------------------------------
  ! PROJ_DIAMETER   : projectile diameter                       m

  ! Variables computed in routine RADARSET
  ! ----------------------------------------
  ! SECTION         : projectile section area                   m**2
  ! ELEV_BEAMWIDTH  : elevation beamwidth                       rad
  ! AZIM_BEAMWIDTH  : azimuth beamwidth                         rad
  ! RANGE_RES       : range resolution                          m
  ! RRATE_RES       : range rate resolution                     m/s
  ! RCSMAX          : maximum radar cross section               m**2
  ! RCSMAXDB        :     "       "     "      "                dBsm
  ! STN_0           : free space S/N at 1 NM for max RCS        dB
  ! RCS_NORM        : normalized RCS ([0,1])                    n/a
  ! STNDB           : S/N ratio                                 dB
  ! PROB_DETECTION  : probability of detection                  n/a
  ! ATTENUATION     : attenuation due to weather                db/km
```

```
C------ Declare radar parameter types

 REAL
      .          RADAR_POWER      , ANTENNA_GAIN     , WAVE_LENGTH
      .,         PROJ_DIAMETER    , RECEIVER_FREQ    , NOISE_FIGURE
      .,         TOTAL_LOSSES     , FFT_LENGTH       , ELEV_BEAMWIDTH
      .,         AZIM_BEAMWIDTH   , WEATHER          , SECTION
      .,         RANGE_RES        , RRATE_RES        , RCSMAX
      .,         RCSMAXDB         , STN_0            , RCS_NORM
      .,         STNDB            , PROB_DETECTION   , ATTENUATION
      .,         X_BAND(2)        , KU_BAND(2)       , K_BAND(2)
      .,         KA_BAND(2)       , Q_BAND(2)        , V_BAND(2)
      .,         W_BAND(2)

C------ Common block for radar parameters

 COMMON /RADAR_COM/
      .          RADAR_POWER      , ANTENNA_GAIN     , WAVE_LENGTH
      .,         PROJ_DIAMETER    , RECEIVER_FREQ    , NOISE_FIGURE
      .,         TOTAL_LOSSES     , FFT_LENGTH       , ELEV_BEAMWIDTH
      .,         AZIM_BEAMWIDTH   , WEATHER          , SECTION
      .,         RANGE_RES        , RRATE_RES        , RCSMAX
      .,         RCSMAXDB         , STN_0            , RCS_NORM
      .,         STNDB            , PROB_DETECTION   , ISEED
      .,         ATTENUATION      , X_BAND           , KU_BAND
      .,         K_BAND           , KA_BAND          , Q_BAND
      .,         V_BAND           , W_BAND
C------ Default values for radar parameters

 DATA
      .          RADAR_POWER      , ANTENNA_GAIN     , WAVE_LENGTH
      .,         PROJ_DIAMETER    , RECEIVER_FREQ    , NOISE_FIGURE
      .,         TOTAL_LOSSES     , FFT_LENGTH       , ELEV_BEAMWIDTH
      .,         AZIM_BEAMWIDTH   , WEATHER          , SECTION          /
      .          200.             , 39.0             , 1.76E-2
      .,         155.E-3          , 0.5E6            , 2.
      .,         9.               , 2048.            , 0.0301
      .,         0.0301           , 0.               , 0.01887          /

 DATA
      .          X_BAND           /  8.E9 ,  12.E9 /
      .,         KU_BAND          / 12.E9 ,  18.E9 /
      .,         K_BAND           / 18.E9 ,  27.E9 /
      .,         KA_BAND          / 27.E9 ,  40.E9 /
      .,         Q_BAND           / 36.E9 ,  46.E9 /
      .,         V_BAND           / 46.E9 ,  56.E9 /
      .,         W_BAND           / 56.E9 , 100.E9 /

C------ Constants
```

```
C------                convention :
C------                x (m)    = y (nm)   * NM2M
C------                y (rad)  = x (deg)  * DEG2RAD
C------                x (deg)  = y (rad)  * RAD2DEG

   REAL                                                , NM2M
       .      PI               , TWOPI                 , LIGHTSPEED
      .,      DEG2RAD          , RAD2DEG

   DATA                                                , NM2M
       .      PI               , TWOPI                 , LIGHTSPEED /
      .,      DEG2RAD          , RAD2DEG               , 1853.
       .      3.141592654      , 6.283185307           , 3.E8       /
      .,      17.4532925E-3    , 57.2957795
C***********************************************************************
```

File: TAR_COM18.FOR

```
C***********************************************************************
C
C VARIABLE DECLARATION AND COMMON BLOCK FOR TAR_MAIN PROGRAM
C TAR_COM18.FOR    ! 02-MAY-1990
C
C***********************************************************************

   CHARACTER*10        ICOFILE, ICFILE, TMPFILE

   INTEGER             OPTION, RUNFLG, RADFLG, RNSEED/223457/
      1,                       SLAYER, NLAYER, MLAYER, ILAYER, KLAYER
      1,                       IMAX, JMAX, KMAX, I, J, K, NCOST(40)
      1,                       ISEED

   REAL                RHOTAB (40), VWXTAB (40), VWYTAB (40)
      1,                       RHOTAB0(40), VWXTAB0(40), VWYTAB0(40)
      1,                       RHOUL  (40), VWXUL  (40), VWYUL  (40)
      1,                       RHOLL  (40), VWXLL  (40), VWYLL  (40)
      1,                       RHOPCT (40), VWXPCT (40), VWYPCT (40)
      1,                       COSTVX (40), COSTVY (40), COSTVZ (40)
      1,                       LAYER, LVX, LVY, LVZ, COSTVZMIN, COSTVZTH
      1,                       RHOSTEP, VWXSTEP, VWYSTEP, XRHO, RHOMIN
      1,                       VWXH0, VWXA0, VWXH1, VWXA1, COSTVZTHSL
      1,                       VWYH0, VWYA0, VWYH1, VWYA1
      1,                       KXER, KVXER, KAXER
      1,                       KYER, KVYER, KAYER
      1,                       KZER, KVZER, KAZER, KRGER, KRRER
      1,
```

```
COMMON / TARCOM1 /          OPTION, RUNFLG, RADFLG, RNSEED
    1                       SLAYER, NLAYER, MLAYER, ILAYER, KLAYER
    1,                      IMAX, JMAX, KMAX, NCOST
    1,                      RHOTAB      , VWXTAB      , VWYTAB
    1,                      RHOTAB0     , VWXTAB0     , VWYTAB0
    1,                      RHOUL       , VWXUL       , VWYUL
    1,                      RHOLL       , VWXLL       , VWYLL
    1,                      RHOPCT      , VWXPCT      , VWYPCT
    1,                      COSTVX      , COSTVY      , COSTVZ
    1,                      LAYER, LVX, LVY, LVZ
    1,                      RHOSTEP, VWXSTEP, VWYSTEP, RHOMIN
    1,                      VWXH0, VWXA0, VWXH1, VWXA1
    1,                      VWYH0, VWYA0, VWYH1, VWYA1
    1,                      KXER, KVXER, KAXER
    1,                      KYER, KVYER, KAYER
    1,                      KZER, KVZER, KAZER, KRGER, KRRER
    1,                     ISEED

DATA OPTION, RADFLG / 2 . 2 /

DATA ICOFILE, ICFILE, TMPFILE / 'ICO', 'IC', 'TMP' /

DATA LAYER / 1000. /

DATA (RHOTAB0(I),I=1,20)
  1/ 1.2245, 1.1095, 1.0051, 0.9082, 0.8184
  1, 0.7357, 0.6559, 0.5872, 0.5218, 0.4656
  1, 0.4112, 0.3616, 0.3118, 0.2629, 0.2259
  1, 0.1929, 0.1640, 0.1423, 0.1206, 0.1029
  1/

DATA VWXH0, VWXA0, VWXH1, VWXA1 / 2200., 10., 5100., 20. /

DATA VWYH0, VWYA0, VWYH1, VWYA1 / 2300.,  5., 3800., 15. /

DATA LVX, LVY, LVZ / 1., 1., 1. /

DATA IMAX, JMAX, KMAX / 50, 20, 20 /

DATA (RHOUL(I),I=1,20)
  1/    1.3000, 1.2000, 1.1000, 1.0000, 0.9000
  1,    0.8000, 0.7500, 0.7000, 0.6000, 0.8000
  1,    0.8000, 0.8000, 0.8000, 0.8000, 0.8000
  1,    0.8000, 0.8000, 0.8000, 0.8000, 0.8000
  1/

DATA (RHOLL(I),I=1,20)
  1/    1.1000, 1.0000, 0.9000, 0.8000, 0.7000
  1,    0.6000, 0.5500, 0.5000, 0.4000, 0.4000
  1,    0.2000, 0.2000, 0.2000, 0.2000, 0.2000
```

```
     1,   0.0500, 0.0500, 0.0500, 0.0500, 0.0500
     1/
      DATA (VWXUL(I),I=1,20)      / 20*25. /
      DATA (VWXLL(I),I=1,20)      / 20* 0. /
      DATA (VWYUL(I),I=1,20)      / 20*20. /
      DATA (VWYLL(I),I=1,20)      / 20* 0. /
      DATA COSTVZTHSL / 0.1 /
      DATA KXER, KVXER, KAXER     / 0.05, 10., 0. /
      DATA KYER, KVYER, KAYER     / 0.05, 10., 0. /
      DATA KZER, KVZER, KAZER     / 0.01, 0.2, 0. /
      DATA KRGER, KRRER           / 0.,    0.      /
```

File: TAR_MAIN18.FOR

```
      PROGRAM TAR_MAIN18                               ! 02-MAY-1990
C*****************************************************************
C
C     MAIN PROGRAM FOR TRAJECTORY ANALYSIS RADAR (TAR).
C
C     OPTION  =(1)            RUN OPTIMIZATION
C             = 2             RUN NOMINAL AND FINAL(s) ONLY
C             = 3             RUN PARAMETER GRID IN ONE LAYER
C
C     RUNFLG  = 1             RUN NOMINAL TRAJECTORY, SAVE NOM VARIABLES
C             = 2             RUN SPECIFIC LAYERS FOR ESTIMATION OR GRID
C             = 3             RUN COMPLETE TRAJECTORY WITH BEST ESTIMATE
C             = 4             RUN CLOSED-LOOP ESTIMATION
C
C     RADFLG  = 0 or (1)      NO RADAR RANDOM NOISE
C               2             RANDOM NOISE ACTIVATED
C
C     THIS PROGRAM CONTROLS 'TAR_SIM.CSL' ACSL DYNAMIC SIMULATION PROGRAM:
C
C        - SPECIFY A 'ZZCOM' ICFILE TO INITIALIZE ACSL RUN
C        - DETERMINE RUN PARAMETERS (EG, WIND AND RHO PROFILES)
C        - SET RUN PARAMETERS THRU SET_ACSL_PARAM SUBROUTINE
C        - RUN ACSL (CALL ZZSIML) WITH THOSE SET PARAMETERS
C        - RETRIEVE DATA FROM ACSL THRU GET_ACSL_PARAM SUBROUTINE
C
```

```
C PARAMETERS PASSED TO TAR_SIM BEFORE EACH RUN (SET_ACSL_PARAM):
C
C RUNFLG                        AFFECT TERMT AND DATA LOGGING IN ACSL RUN
C RADFLG, RNSEED                RANDOM NOISE ACTIVATION AND SEED
C NLAYER                        NUMBER OF ATMOSPHERIC LAYERS TO BE RUN
C LAYER                         SIZE (IN METERS) OF EACH ATMOSPHERIC LAYER
C RHOTAB                        BREAKPOINT TABLE FOR DYNAMIC PRESSURE RHO
C VWXTAB                        BREAKPOINT TABLE FOR WIND IN GUN PLANE
C VWYTAB                        BREAKPOINT TABLE FOR WIND NORMAL TO GUN PLANE
C LVX, LVY, LVZ                 WEIGHTS OF VELOCITY ERRORS IN COST FUNCTIONS
C
C PARAMETERS RETRIEVED FROM TAR_SIM AFTER EACH RUN (GET_ACSL_PARAM):
C
C MLAYER                        LAYER INDEX OF (NOMINAL RUN) APEX
C COSTVX                        RMS OF X-AXIS ERROR (POS AND VEL), PER LAYER
C COSTVY                        RMS OF Y-AXIS ERROR (POS AND VEL), PER LAYER
C COSTVZ                        RMS OF Z-AXIS ERROR (POS AND VEL), PER LAYER
C NCOST                         POINTS PER LAYER USED IN COST CALCULATION
C
C KEY ESTIMATION PARAMETERS DISPLAYED:
C
C RHOPCT                        PERCENT ERROR IN RHO
C VWXPCT                        PERCENT ERROR IN VWX
C VWYPCT                        PERCENT ERROR IN VWY
C DIMPAC                        HORIZONTAL RANGE ERROR AT GROUND IMPACT
C
C CONSTRAINTS ON PARAMETER SPACE ARE:
C
C RHOUL, RHOLL
C VWXUL, VWXLL
C VWYUL, VWYLL
C
C NOMINAL WIND BREAKPOINTS COMPUTED FROM A SMOOTH CURVE:
C
C VWXH0, VWXA0                  WIND X:  A0 IS CST WIND AMPLITUDE BELOW ALT H0,
C VWXH1, VWXA1
C
C VWYH0, VWYA0                  WIND Y:  A0 IS CST WIND AMPLITUDE BELOW ALT H0,
C VWYH1, VWYA1
C
C****************************************************************


C****************************************************************
C
C IMPORTANT ATMOSPHERIC LAYER INDEXES AND TERMINOLOGIES:
C
C VARIABLE          SOURCE                 DEFINITION
C --------          ------                 ----------
C
C LAYER             TAR_MAIN          SIZE OF EACH LAYER IN METERS
```

```
C MLAYER             TAR_SIM          LAYER OF (NOMINAL RUN) APEX
C SLAYER             TAR_MAIN         STARTING LAYER INDEX (1-MLAYER) FOR SIM
C
C ICFILE             TAR_MAIN         ZZCOM FILE TO START @ LAYER 1
C TMPFILE            TAR_MAIN         ZZCOM FILE TO START @ LAYER "SLAYER"
C NEWRUN          Arg to RUN_ACSL     REGENERATE 'TMPFILE' TO RUN @ "SLAYER"
C
C ILAYER             TAR_MAIN         CURRENT LAYER INDEX  (1-MLAYER)
C KLAYER             TAR_MAIN         ILAYER + 1, INDEX TO MET TABLES
C
C*************************************************************************

  IMPLICIT NONE
  INCLUDE 'TAR_COM18.FOR'
C------------------------------------------------------------------------
C------   Initialize ACSL---------------------------------------------------
C------------------------------------------------------------------------

  CALL ZZDLOC
  RUNFLG = 1          ! Always run Nominal first
C------------------------------------------------------------------------
C------ User defined run parameters---------------------------------------
C------------------------------------------------------------------------

 100      CALL GET_USER_PARAM
C************************************************************************
C------ Perform Nominal Run first time (RUNFLG=1) only*********************
C************************************************************************

  IF (RUNFLG.EQ.1) THEN

      PRINT 501
 501  -       FORMAT(1X,70('-'),/,1X,'Nominal run',/,1X,70('-'))
      CALL RUN_ACSL(0)                ! Load Param/Run ACSL/Get MLAYER, ...

  END IF

  GOTO (1000, 2000, 3000) OPTION


C************************************************************************
C------ Run Optimization/Parameter Estimate if OPTION  = 1****************
C************************************************************************

 1000      PRINT     502
 502       FORMAT(1X,70('-'),/,1X,'Estimation Run',/,1X,70('-'))
```

```
C---------------------------------------------------------------------
C------   Run 3-axis closed-loop estimation of rho and wind
C---------------------------------------------------------------------

  RUNFLG = 4
  IMAX   = 2

C------ Number of iterations in DO loop

  PRINT    * , ' Change number of iterations IMAX ? ', IMAX
  READ(5,*) IMAX

C------ Guess of rho

  PRINT   *,' Enter first guess of RHOTAB ?'
  PRINT  10, 'RHOTAB     =', (RHOTAB (I),I=1,20)      ! Current Estimate
  READ(5,*)   (RHOTAB(I),I=1,20)

C------ Guess of wind

  PRINT   *,' Enter first guess of VWXTAB and VWYTAB ?'
  PRINT  10, 'VWXTAB     =', (VWXTAB (I),I=1,20)      ! Current Estimate
  READ(5,*)   (VWXTAB(I),I=1,20)
  PRINT  10, 'VWYTAB     =', (VWYTAB (I),I=1,20)      ! Current Estimate
  READ(5,*)   (VWYTAB(I),I=1,20)

 10        FORMAT(1X,A11,3X,10(F5.2,1X),:,2(/15X,10(F5.2,1X)))

C------ Perform 1st closed-loop run

  I = 1
  PRINT 511, I
 511       FORMAT(1X,70('-'),/,1X,'Iteration ',I)

  CALL RUN_ACSL(0)                  ! Load Param/Run ACSL/Get Cost Function

C------ Perform remaining runs

  DO I = 2, IMAX                    ! Maximum number of iterations
     PRINT 511, I
     CALL RUN_ACSL(1)               ! Load Param/Run ACSL/Get Cost Function
  END DO


C*********************************************************************
C------ Run Final(s)
C*********************************************************************

 2000      PRINT    503
 503       FORMAT(1X,70('-'),/,1X,'Final Run',/,1X,70('-'))
```

```
      RUNFLG = 3
C 2050    CALL SET METS
      CALL RUN_ACSL(0)
                                     ! Select METS again
C GOTO 2050
      PRINT *, ' TAR> Rerun nominal ? (1:yes, 0:no) : '
      READ(5,*) I

      IF (I.EQ.1) THEN
        CALL ZZSVRS2(0, ICOFILE)   ! restore startup values
        RUNFLG = 1
      ELSE
        CALL ZZSVRS2(0, ICFILE)    ! restart estimation from clean TMPFILE
        CALL ZZSVRS2(1, TMPFILE)
      END IF

      CALL GET_ACSL_PARAM (
     1          MLAYER   , COSTVX   , COSTVY   , COSTVZ   , NCOST
     1,         KXER     , KVXER    , KAXER    , KYER     , KVYER
     1,         KAYER    , KZEP     , KVZER    , KAZER    , KRGER
     1,         KRRER    , RHOTAB   , VWXTAB   , VWYTAB   )

      GOTO 100

C*******************************************************************
C------ Run KLAYER layer grid if OPTION  = 3n, n = KLAYER
C*******************************************************************

3000    PRINT     *  ,  ' TAR> Grid Run ..........'
      WRITE(40,*),  ' TAR> Grid Run ..........'
      RUNFLG = 2

C------ First, Re-generate TMPFILE up to SLAYER

      PRINT     * ,  ' TAR> Which layer to run grid ? '
      READ(5,*) ILAYER

      PRINT     * ,  ' TAR> Generating TMPFILE to start @ layer ', SLAYER
      WRITE(40,*),   ' TAR> Generating TMPFILE to start @ layer ', SLAYER

      PRINT    81 ,  ' Change RHOTAB =   ', (RHOTAB(I),I=1,ILAYER)
      READ(5,*) (RHOTAB(I),I=1,ILAYER)

      PRINT    81 ,  ' Change VWXTAB =   ', (VWXTAB(I),I=1,ILAYER)
      READ(5,*) (VWXTAB(I),I=1,ILAYER)

      PRINT    81 ,  ' Change VWYTAB =   ', (VWYTAB(I),I=1,ILAYER)
      READ(5,*) (VWYTAB(I),I=1,ILAYER)
```

```
81        FORMAT(/A18,<ILAYER>F10.3,' ?')

  SLAYER = 1                          ! Start @ layer 1
  NLAYER = ILAYER - 1                 ! Run up to SLAYER
  CALL RUN_ACSL(1)                    ! Generate TMPFILE

C------ Grid run at layer SLAYER

  SLAYER = ILAYER
  KLAYER = ILAYER + 1
  NLAYER = 1

  PRINT  91, IMAX, JMAX, KMAX
  READ(5,*)  IMAX, JMAX, KMAX
91        FORMAT(/1X,'TAR> Enter IMAX, JMAX, KMAX for Grid Run :',3I5)

  PRINT  92, RHOSTEP, VWXSTEP, VWYSTEP
  READ(5,*)  RHOSTEP, VWXSTEP, VWYSTEP
92        FORMAT(/1X,'TAR> Enter RHOSTEP, VWXSTEP, VWYSTEP :',3F10.3)

  PRINT  93, RHOLL(KLAYER), VWXLL(KLAYER), VWYLL(KLAYER), KLAYER
  READ(5,*)  RHOLL(KLAYER), VWXLL(KLAYER), VWYLL(KLAYER)
93        FORMAT(/1X,'TAR> Enter RHOLL, VWXLL, VWYLL        :',3F10.3)

  DO 3200 I = 0, IMAX-1
  DO 3200 J = 0, JMAX-1
  DO 3200 K = 0, KMAX-1

     IF (IMAX.GT.1) RHOTAB(KLAYER) = RHOLL(KLAYER) + RHOSTEP*I
     IF (JMAX.GT.1) VWXTAB(KLAYER) = VWXLL(KLAYER) + VWXSTEP*J
     IF (KMAX.GT.1) VWYTAB(KLAYER) = VWYLL(KLAYER) + VWYSTEP*K

     CALL RUN_ACSL(0)       ! Load Param/Run ACSL/Get Cost Function
     CALL PRNT_COST(4)      ! Print results of grid run

3200      CONTINUE

  GOTO 100                  ! Select OPTION again

  END

  SUBROUTINE RUN_ACSL(NEWRUN)
C*************************************************************************
C
C SUBROUTINE TO INTERFACE WITH ACSL DYNAMIC SIMULATION TAR_SIM PROGRAM:
C
C - PERFORM AN 'ACSL> RESTORE' FILE (STARTING POINT)
C - LOAD RELEVANT OPTIMIZATION PARAMETERS
C - RUN ACSL
C - RETRIEVE COST FUNCTION DATA FROM ACSL RUN
```

```
C
C TWO WAYS TO CHANGE ACSL PARAMETERS PRIOR TO A RUN:
C
C - INTERACTIVE THRU ACSL>, ONLY FOR 1ST RUN AND SENSITIVITY RUNS
C - METS PARAMETERS THRU SET_ACSL_PARAM
C
C PARAMETER NEWRUN:
C
C         0:      NO ZZCOM FILE SAVED
C         1:      ZZCOM SAVED INTO TMPFILE
C***************************************************************************

   IMPLICIT NONE
   INCLUDE 'TAR_COM18.FOR'
   INTEGER  NEWRUN
   CHARACTER*10 FILE
   INTEGER ICORRECT/1/, NBPMAX/1600/
   LOGICAL CLMET/.FALSE./
   REAL TSTP/-35./

C---------------------------------------------------------------------------
C------   ZZCOM File handling prior to run ACSL ----------------------------
C---------------------------------------------------------------------------

C------ RUNFLG=1:  Allow user to make parameter changes directly in ACSL

   IF (RUNFLG.EQ.1) THEN
      CLMET = .FALSE.
   END IF

C------ RUNFLG=2:  Restore TMPFILE file

   IF (RUNFLG.EQ.2) THEN
            FILE = TMPFILE
            IF (ILAYER.EQ.1) FILE=ICFILE
      CALL ZZSVRS2(0, FILE)           ! Restor file
   END IF

C------    RUNFLG=3:  Restore ICFILE file, allow temporary ACSL changes

   IF (RUNFLG.EQ.3) THEN
      IF (CLMET) THEN
         FILE  = TMPFILE
         TSTP  = 200.
         CLMET = .FALSE.
      ELSE
         FILE = ICFILE
      END IF
      CALL ZZSVRS2(0, FILE)          ! Equ to ACSL> RESTOR 'ICFILE'
   END IF
```

```
C------   RUNFLG=4:  Restore TMPFILE file, allow temporary ACSL changes

  IF (RUNFLG.EQ.4) THEN
     CLMET = .TRUE.
C    IF (NEWRUN.EQ.0) THEN
C       PRINT  *, ' TAR> Enter TSTP for closed-loop runs:', TSTP
C       READ(5,*) TSTP
C    END IF
     FILE = TMPFILE
     CALL ZZSVRS2(0, FILE)          ! Equ to ACSL> RESTOR 'TMPFILE'
  END IF

C-----------------------------------------------------------------------
C------ Load MET param into ZZCOM / Run ACSL / Get Cost Function Data from
C-----------------------------------------------------------------------

  CALL SET_ACSL_PARAM (
     1         RUNFLG   , RADFLG   , RNSEED   , NLAYER   , RHOTAB
     1,        VWXTAB   , VWYTAB   , LVX      , LVY      , LVZ
     1,        VWXH0    , VWXA0    , VWXH1    , VWXA1    , VWYH0
     1,        VWYA0    , VWYH1    , VWYA1    , CLMET    , TSTP
     1,        KXER     , KVXER    , KAXER    , KYER     , KVYER
     1,        KAYER    , KZER     , KVZER    , KAZER    , KRGER
     1,        KRRER    )

       IF (RUNFLG.NE.2) CALL ZZEXEC       ! ACSL user interface

   IF (RUNFLG.EQ.1) THEN
      CALL ZZSVRS2(1, ICFILE)        ! Equ to ACSL> SAVE 'ICFILE'
      CALL ZZSVRS2(1, ICOFILE)       ! Equ to ACSL> SAVE 'ICOFILE'
      CALL ZZSVRS2(1, TMPFILE)       ! Equ to ACSL> SAVE 'TMPFILE'
   END IF

   CALL ZZSIML                       ! Run ACSL dynamic simulation

   CALL GET_ACSL_PARAM (
      1        MLAYER   , COSTVX   , COSTVY   , COSTVZ   , NCOST
      1,       KXER     , KVXER    , KAXER    , KYER     , KVYER
      1,       KAYER    , KZER     , KVZER    , KAZER    , KRGER
      1,       KRRER    , RHOTAB   , VWXTAB   , VWYTAB   )

        IF (RUNFLG.EQ.1 .OR. RUNFLG.EQ.3) CALL ZZEXEC     ! ACSL user inter

C-----------------------------------------------------------------------
C------   ZZCOM File handling after completion of ACSL run
C-----------------------------------------------------------------------

   IF (RUNFLG.EQ.1) THEN
          CALL SAVENOMINAL( ICFILE )   ! Save all xxxNOM arrays into ZZCOM
     ! Make TMPFILE identical to ICFILE
```

```
      CALL ZZSVRS2(0, ICFILE)
      CALL ZZSVRS2(1, TMPFILE)
    END IF

    IF (CLMET) THEN
      CALL SAVECORRECTION( TMPFILE , NBPMAX , NEWRUN )
      CALL GET_ACSL_PARAM (
     1          MLAYER   , COSTVX   , COSTVY   , COSTVZ   , NCOST
     1,         KXER     , KVXER    , KAXER    , KYER     , KVYER
     1,         KAYER    , KZER     , KVZER    , KAZER    , KRGER
     1,         KRRER    , RHOTAB   , VWXTAB   , VWYTAB   )
    ELSE IF (NEWRUN.EQ.0) THEN
      RETURN
    ELSE
      CALL ZZSVRS2(1, TMPFILE)
    END IF

    RETURN
    END

    SUBROUTINE GET_USER_PARAM
C************************************************************************
C
C REQUESTS THE FOLLOWING RUN PARAMETERS:
C
C OPTION                           RUN OPTION
C RADFLG, RNSEED                   NOISE OPTION AND SEED FOR RN GEN
C RHOUL, RHOLL                     RHO LIMITS FOR EACH LAYER
C VWXUL, VWXLL                     VWX LIMITS FOR EACH LAYER
C VWYUL, VWYLL                     VWY LIMITS FOR EACH LAYER
C VWXH0, VWXA0                     WIND PROFILE PARAMETERS
C VWXH1, VWXA1                     WIND PROFILE PARAMETERS
C VWYH0, VWYA0                     WIND PROFILE PARAMETERS
C VWYH1, VWYA1                     WIND PROFILE PARAMETERS
C
C THE FOLLOWING PARAMETERS CAN BE CHANGED 1ST TIME ONLY (RUNFLG=1):
C
C LAYER                            ALTITUDE LAYER SIZE
C LVX, LVY, LVZ                    VELOCITY ERROR WEIGHTS IN COST FCTS
C
C************************************************************************

      IMPLICIT NONE
      INCLUDE 'TAR_COM18.FOR'

      OPTION = 1
      PRINT  1, OPTION, RADFLG, RNSEED
      READ(5,*) OPTION, RADFLG, RNSEED

      IF (OPTION.EQ.0) STOP
```

```
C IF (RUNFLG.EQ.1) THEN
C PRINT    5, LAYER, LVX, LVY, LVZ, COSTVZTHSL
C READ(5,*)  LAYER, LVX, LVY, LVZ, COSTVZTHSL
C END IF
  1        FORMAT(/1X,'OPTION =',I2,5X,'RADFLG =',I2,3X,'RNSEED      ='
     1, I10,'?')
  5        FORMAT(/1X,'LAYER  =',F5.0,2X,'LVX, LVY, LVZ, COSTVZTHSL ='
     1,    3(F5.1,2X),F10.5,'?')

C------ RHO Limits

   IF (RUNFLG.EQ.1) THEN
            DO I = 1, 40
               RHOTAB(I)  =  RHOTAB0(I)
      END DO
   END IF

C PRINT    *,' Enter RHOUL and RHOLL ?'
C PRINT   10, 'RHOUL      =', (RHOUL   (I),I=1,20)     ! Upper limits
C PRINT   10, 'RHOTAB0    =', (RHOTAB0(I),I=1,20)      ! True RHO
C PRINT   10, 'RHOTAB     =', (RHOTAB (I),I=1,20)      ! Current Estimate
C PRINT   10, 'RHOLL      =', (RHOLL   (I),I=1,20)     ! Lower limits
C READ(5,*)   (RHOUL   (I),I=1,20)
C READ(5,*)   (RHOLL   (I),I=1,20)

 10        FORMAT(1X,A11,3X,10(F5.2,1X),:,2(/15X,10(F5.2,1X)))

C------ VWX, VWY Nominal and Limits

   PRINT  15, VWXH0, VWXA0, VWXH1, VWXA1
   READ(5,*)  VWXH0, VWXA0, VWXH1, VWXA1
   PRINT  16, VWYH0, VWYA0, VWYH1, VWYA1
   READ(5,*)  VWYH0, VWYA0, VWYH1, VWYA1
   CALL GET_WIND_TABLE(RUNFLG-1)

 15        FORMAT(/1X,' (VWXH0 VWXA0), (VWXH1 VWXA1) =', 2(F10.0,F7.2),'?')
 16        FORMAT(/1X,' (VWYH0 VWYA0), (VWYH1 VWYA1) =', 2(F10.0,F7.2),'?')

C PRINT    *,' Enter VWXUL and VWXLL ?'
C PRINT   10, 'VWXUL      =', (VWXUL   (I),I=1,20)     ! Upper limits
C PRINT   10, 'VWXTAB0    =', (VWXTAB0(I),I=1,20)      ! True VWX
C PRINT   10, 'VWXTAB     =', (VWXTAB (I),I=1,20)      ! Current Estimate
C PRINT   10, 'VWXLL      =', (VWXLL   (I),I=1,20)     ! Lower limits
C READ(5,*)   (VWXUL   (I),I=1,20)
C READ(5,*)   (VWXLL   (I),I=1,20)

C           PRINT    *,' Enter VWYUL and VWYLL ?'     ! Upper limits
C PRINT   10, 'VWYUL      =', (VWYUL   (I),I=1,20)     ! True VWY
C PRINT   10, 'VWYTAB0    =', (VWYTAB0(I),I=1,20)
```

```
C PRINT  10,  'VWYTAB     =', (VWYTAB (I),I=1,20)    ! Current Estimate
C PRINT  10,  'VWYLL      =', (VWYLL  (I),I=1,20)    ! Lower limits
C READ(5,*)   (VWYUL  (I),I=1,20)
C READ(5,*)   (VWYLL  (I),I=1,20)

  RETURN
  END

  SUBROUTINE GET_WIND_TABLE(K)
C**********************************************************************
C
C SUBROUTINE TO COMPUTE BREAKPOINTS FOR VWXTAB AND VWYTAB, BASED ON
C
C - LAYER
C - VWXH0, VWXA0
C - VWXH1, VWYH1
C
C USING polynomial CURVE SHAPE.
C
C IF K=0, LOAD VWXTAB INTO VWXTAB0 AND VWYTAB INTO VWYTAB0.
C
C**********************************************************************

  IMPLICIT NONE
  INCLUDE 'TAR_COM18.FOR'
  REAL ALT, DA, DH

C------ VWXTAB

  DA   = VWXA1 - VWXA0

  DO I=1,20                    ! Loop on Breakpoints

     ALT = LAYER*(I-1)                       ! Altitude at breakpoint
          DH  = (ALT-VWXH0)/(VWXH1-VWXH0)
     IF (ALT.LT.VWXH0) THEN                        ! Constant wind below H0
          VWXTAB(I)=VWXA0
     ELSE IF (ALT.GT.VWXH1) THEN                   ! Constant wind above H1
          VWXTAB(I)=VWXA1
     ELSE
       VWXTAB(I)=VWXA0 + 3*DA*(DH)**2 - 2*DA*(DH)**3
     END IF
          IF (K.EQ.0) VWXTAB0(I) = VWXTAB(I)     ! True wind parameters

  END DO

C------ VWYTAB
```

```
DA    = VWYA1 - VWYA0
DO I=1,20                   ! Loop on Breakpoints
   ALT = LAYER*(I-1)                         ! Altitude at breakpoint
        DH   = (ALT-VWYH0)/(VWYH1-VWYH0)
   IF (ALT.LT.VWYH0) THEN                    ! Constant wind below H0
          VWYTAB(I)=VWYA0
   ELSE IF (ALT.GT.VWYH1) THEN               ! Constant wind above H1
          VWYTAB(I)=VWYA1
   ELSE
     VWYTAB(I)=VWYA0 + 3*DA*(DH)**2 - 2*DA*(DH)**3
   END IF
         IF (K.EQ.0) VWYTABO(I) = VWYTAB(I)     ! True wind

END DO
RETURN
END

SUBROUTINE PRNT_COST(K)
C*******************************************************************
C
C SUBROUTINE TO PRINT RESULTS AT LAYER "KLAYER"
C
C*******************************************************************

IMPLICIT NONE
INCLUDE 'TAR_COM18.FOR'

I = KLAYER        ! Index to table

RHOPCT(I) = (RHOTAB(I)-RHOTAB0(I))/RHOTAB0(I)
VWXPCT(I) = (VWXTAB(I)-VWXTAB0(I))/VWXTAB0(I)
VWYPCT(I) = (VWYTAB(I)-VWYTAB0(I))/VWYTAB0(I)

GOTO (100, 200, 300, 400) K

100      PRINT     991 , K, ILAYER, RHOPCT(I), SQRT(COSTVZ(ILAYER))
 WRITE(40,991), K, ILAYER, RHOPCT(I), SQRT(COSTVZ(ILAYER))
 RETURN

200      PRINT     991 , K, ILAYER, VWXPCT(I), SQRT(COSTVX(ILAYER))
 WRITE(40,991), K, ILAYER, VWXPCT(I), SQRT(COSTVX(ILAYER))
 RETURN

300      PRINT     991 , K, ILAYER, VWYPCT(I), SQRT(COSTVY(ILAYER))
```

```
      WRITE(40,991), K, ILAYER, VWYPCT(I), SQRT(COSTVY(ILAYER))
      RETURN
400        PRINT    995 , K, ILAYER
     1,                      RHOPCT(I), SQRT(COSTVZ(ILAYER))
     1,                   VWXPCT(I), SQRT(COSTVX(ILAYER))
     1,                   VWYPCT(I), SQRT(COSTVY(ILAYER))

991        FORMAT(I2,I4,4X,2F10.3,';')
995        FORMAT(I2,I4,4X,6F10.3,';')

      RETURN
      END


      SUBROUTINE SET METS
C***********************************************************************
C
C THIS SUBROUTINE ALLOWS CHANGE TO MET PARAMETERS FOR COMPARISON
C RUN TO NOMINAL
C
C***********************************************************************

      IMPLICIT NONE
      INCLUDE 'TAR_COM18.FOR'
      INTEGER IANS

      PRINT  *, ' MODIFY WIND PARAM (0) OR TAB (1) '
      READ(5,*)   IANS

C------ Wind

      IF (IANS.EQ.1) GOTO 100

 1          FORMAT(/A45,2(F8.1,2X,F5.2))

      PRINT  1, ' TAR> MODIFY (VWXH0 VWXA0), (VWXH1 VWXA1) ? '
     1, VWXH0, VWXA0, VWXH1, VWXA1

      READ(5,*)   VWXH0, VWXA0, VWXH1, VWXA1

      PRINT  1, ' TAR> MODIFY (VWYH0 VWYA0), (VWYH1 VWYA1) ? '
     1, VWYH0, VWYA0, VWYH1, VWYA1

      READ(5,*)   VWYH0, VWYA0, VWYH1, VWYA1

      CALL GET_WIND_TABLE(1)
      GOTO 200

C------
```

```
2        FORMAT(/A20,10F5.2,:,2(/20X,10(F5.2,1X)))

100      PRINT  2, ' TAR> VWX = ? ',(VWXTAB(I),I=1,20)
 READ(5,*)  (VWXTAB(I),I=1,20)

 PRINT  2, ' TAR> VWY = ?',(VWYTAB(I),I=1,20)
 READ(5,*)  (VWYTAB(I),I=1,20)

C------ Change RHO

200      PRINT  2, ' TAR> RHO = ?',(RHOTAB(I),I=1,20)
 READ(5,*)  (RHOTAB(I),I=1,20)

 RETURN
 END
C*********************************************************************

C*********************************************************************
C
      REAL FUNCTION FLNEAR( NBPMAX, NBP , TAB , INP )
C
C     NBPMAX : maximum number of breakpoints
C     NBP    : current number of breakpoints
C     TAB    : table of breakpoints
C              TAB(1:NBPMAX)             : values of dependent variable
C              TAB(NBPMAX+1:2*NBPMAX)    : values of independent variable
C     INP    : input value of independent variable
C     The output is the dependent variable value corresponding to INP.
C
C*********************************************************************

      IMPLICIT NONE
      REAL TAB(*), INP
      INTEGER NBPMAX, NBP, I

C---- Interpolate/extrapolate using the first slope

      IF (INP.LE.TAB(NBPMAX+2)) THEN
        FLNEAR = TAB(1) + (INP-TAB(NBPMAX+1)) * (TAB(2)-TAB(1))
     /                    / (TAB(NBPMAX+2)-TAB(NBPMAX+1))
        RETURN
      END IF

C---- Find index of independent variable value greater than input value

      DO I = 3 , NBP-1
        IF (INP.LE.TAB(NBPMAX+I)) GOTO 100
      END DO

C---- Interpolate (extrapolation using last slope for input values
```

```
C---- larger than last breakpoint value)

 100  CONTINUE
      FLNEAR = TAB(I-1) + (INP-TAB(NBPMAX+I-1)) * (TAB(I)-TAB(I-1))
                          (TAB(NBPMAX+I)-TAB(NBPMAX+I-1))

      RETURN
      END
C**********************************************************************

C**********************************************************************
C
      SUBROUTINE LSQ_POLY2( C , A , B , N )
C
C     This routine computes the coefficients of the quadratic polynomial
C     solution of a least square approximation of the specified data
C     points (Ai,Bi).
C
C     Output:
C
C     C[3]   = vector of polynomial coefficients
C                 poly(a) = C(3) + C(2)*a + C(1)*a**2
C
C
C     Inputs:
C
C     A[N]   : vector of values of independent variable
C
C     B[N]   : vector of values of dependent variable
C
C     N      : number of data points
C
C**********************************************************************

      IMPLICIT NONE

      INTEGER N
      REAL C(3), A(N), B(N)

      REAL AMAT(3,3), BMAT(3), AMAT_INV(3,3), DET_AMAT
      INTEGER I, K
C----------------------------------------------------------------------
C------ Compute AMAT
C----------------------------------------------------------------------

C------ Compute 1st column of AMAT

      DO K = 1 , 3
         AMAT(K,1) = 0.0
         DO I = 1 , N
```

```
          AMAT(K,1) = AMAT(K,1) + A(I)**(5-K)
       END DO ! I
    END DO ! K
C------ Compute 2nd column of AMAT
    AMAT(1,2) = AMAT(2,1)
    AMAT(2,2) = AMAT(3,1)
    AMAT(3,2) = 0.0
    DO I = 1 , N
       AMAT(3,2) = AMAT(3,2) + A(I)
    END DO ! I
C------ Compute last column of AMAT
    AMAT(1,3) = AMAT(2,2)
    AMAT(2,3) = AMAT(3,2)
    AMAT(3,3) = N
C---------------------------------------------------------------------
C------ Compute BMAT
C---------------------------------------------------------------------
    BMAT(1) = 0.0
    BMAT(2) = 0.0
    BMAT(3) = 0.0
    DO I = 1 , N
       BMAT(1) = BMAT(1) + B(I)*A(I)**2
       BMAT(2) = BMAT(2) + B(I)*A(I)
       BMAT(3) = BMAT(3) + B(I)
    END DO ! I
C---------------------------------------------------------------------
C------ Invert AMAT
C---------------------------------------------------------------------
    CALL INVERT3BY3( AMAT , AMAT_INV , DET_AMAT )
C---------------------------------------------------------------------
C------ Compute polynomial coefficients
C---------------------------------------------------------------------
    DO I = 1 , 3
       C(I) = 0.0
       DO K = 1 , 3
          C(I) = C(I) + AMAT_INV(I,K)*BMAT(K)
       END DO ! K
    END DO ! I
    RETURN
    END
C*********************************************************************
```

```
C*********************************************************************
C
  SUBROUTINE INVERT3BY3( A , A_INV , DET_A )
C
C This routine inverts a 3x3 matrix A and returns:
C - A_INV, the matrix inverse of A
C - DET_A, the determinant of A; DET_A is set to zero if A is almost
C   singular.
C
C*********************************************************************

  IMPLICIT NONE

  REAL A(3,3), A_INV(3,3), DET_A
  REAL*8 D_A(3,3), D_DET_A
  REAL*8 COF(3,3), EPSILON/1.D-20/
  INTEGER I, J

C------ Transfer matrix A into work array

  DO I = 1 , 3
  DO J = 1 , 3
     D_A(I,J) = A(I,J)
  END DO
  END DO

C------ Compute determinant of A

  D_DET_A = D_A(1,1)*D_A(2,2)*D_A(3,3)
  1       + D_A(2,1)*D_A(3,2)*D_A(1,3)
  1       + D_A(1,2)*D_A(2,3)*D_A(3,1)
  1       - D_A(3,1)*D_A(2,2)*D_A(1,3)
  1       - D_A(2,1)*D_A(1,2)*D_A(3,3)
  1       - D_A(3,2)*D_A(2,3)*D_A(1,1)

  DET_A   = D_DET_A

C------ Test for singularity

  IF (ABS(D_DET_A).LE.EPSILON) THEN
     DET_A = 0.0
     RETURN
  END IF

C------ Compute the matrix of cofactors of A

  COF(1,1) =   D_A(2,2)*D_A(3,3) - D_A(3,2)*D_A(2,3)
  COF(2,1) = - D_A(1,2)*D_A(3,3) + D_A(3,2)*D_A(1,3)
  COF(3,1) =   D_A(1,2)*D_A(2,3) - D_A(2,2)*D_A(1,3)
```

```
      COF(1,2) = - D_A(2,1)*D_A(3,3) + D_A(3,1)*D_A(2,3)
      COF(2,2) =   D_A(1,1)*D_A(3,3) - D_A(3,1)*D_A(1,3)
      COF(3,2) = - D_A(1,1)*D_A(2,3) + D_A(2,1)*D_A(1,3)

      COF(1,3) =   D_A(2,1)*D_A(3,2) - D_A(3,1)*D_A(2,2)
      COF(2,3) = - D_A(1,1)*D_A(3,2) + D_A(3,1)*D_A(1,2)
      COF(3,3) =   D_A(1,1)*D_A(2,2) - D_A(2,1)*D_A(1,2)

C------ Compute the matrix inverse of A

      DO I = 1 , 3
      DO J = 1 , 3
         A_INV(I,J) = COF(J,I)/D_DET_A
      END DO
      END DO

      RETURN
      END
C*********************************************************************

C*********************************************************************
C
      SUBROUTINE PLOTSMOOTHED( SMOOTHED, X, Y, N)
C
C Inputs:
C
C SMOOTHED : smoothed dependent variable (dim N)
C X        : independent variable (dim N)
C Y        : dependent variable before smoothing (dim N)
C
C*********************************************************************

      INCLUDE 'COMPLOT'

      INTEGER N
      REAL SMOOTHED(*), X(*), Y(*)
      DATA DATLEN/1600/

      NAME(115) = 'XSMOOTH'
      NAME(116) = 'YSMOOTH'
      NAME(117) = 'YNONSM'

      DO I = 1 , N
         CALL SAVEDATA( X(I)          , DATLEN, I, 115)
         CALL SAVEDATA( SMOOTHED(I)   , DATLEN, I, 116)
         CALL SAVEDATA( Y(I)          , DATLEN, I, 117)
      END DO ! I

      CALL PLOTROUTINE
```

```
      RETURN
      END
C*********************************************************************

C*********************************************************************
C
      SUBROUTINE MOV_AVERAGE( Y1, Y0, N, WP, P)
C
C     This routine compute the sequence Y1 as follows:
C
C     Y0(i), i=1,N   : input sequence
C     W(j), j=1,M    : weights
C
C     Y1(1) = sum{ Y0(j)*W(j) , j=1,3 } / sum{ W(k), k=1,3 }
C     Y1(N) = sum{ Y0(N-j+1)*W(j) , j=1,3 } / sum{ W(k), k=1,3 }
C
C     Y1(i) = [ Y0(i)*WP(i) + sum{ Y0(i-j+1)*W(j) , j=2,min(P,i-1) }
C             + sum{ Y0(i+j-1)*W(j) , j=2,min(P,N-i+1) } ] /
C             [ WP(1) +  sum{ W(k), k=2,min(P,i-1) }     for 2 =< i =< N-1
C             + sum{ W(k), k=2,min(P,N-i+1) } ]
C
C*********************************************************************

      IMPLICIT NONE

      INTEGER N, P
      REAL Y0(N), Y1(N), WP(P)

      INTEGER I, J
      REAL W0, W1

C------ Initialize output sequence

      DO I = 1 , N
        Y1(I) = 0.0
      END DO

C------ Compute sum of weights

      W0 = 0.0
      DO J = 1 , P
        WP(J) = ABS(WP(J))
        W0    = W0 + WP(J)
      END DO
      IF (W0.EQ.0.0) RETURN

C------ Compute output sequence Y1

      Y1(1) = 0.0
```

```
      Y1(N) = 0.0
      W1    = 0.0
      DO J = 1 , 3
         Y1(1) = Y1(1) + Y0(J)*WP(J)
         Y1(N) = Y1(N) + Y0(N-J+1)*WP(J)
         W1    = W1 + WP(J)
      END DO
      IF (W1.NE.0.0) THEN
         Y1(1) = Y1(1) / W1
         Y1(N) = Y1(N) / W1
      END IF

      DO I = 2 , N-1
         Y1(I) = Y0(I)*WP(1)
         W1    = WP(1)
         DO J = 2 , MIN(P,I-1)
            Y1(I) = Y1(I) + Y0(I-J+1)*WP(J)
            W1    = W1 + WP(J)
         END DO
         DO J = 2 , MIN(P,N-I+1)
            Y1(I) = Y1(I) + Y0(I+J-1)*WP(J)
            W1    = W1 + WP(J)
         END DO
         IF (W1.NE.0.0) Y1(I) = Y1(I) / W1
      END DO

      RETURN
      END
C*********************************************************************


C*********************************************************************
C
      SUBROUTINE RADARSET( PROJ_DIAM, KSEED, SETFLAG)
C
C This routine calculates:
C - the range resolution,
C - the radial velocity resolution due to FFT,
C - and the free space S/N at a standartd range of one nautical mile.
C
C*********************************************************************

      INCLUDE 'RADAR_COM18.FOR'
      INTEGER KSEED, SETFLAG
      REAL TRF, PRF, DF
      REAL PROJ_DIAM, AG

C------ Store argument values into common block

      PROJ_DIAMETER = PROJ_DIAM
      ISEED = KSEED
```

```
C------ Ask user radar settings

  IF (SETFLAG.EQ.1) THEN

     PRINT *, ' WEATHER 0 (clear) 1 (rain)  : ', WEATHER
     PRINT *, ' WAVE LENGTH     (m)         : ', WAVE_LENGTH
     PRINT *, ' RECEIVER FREQ (Hz)          : ', RECEIVER_FREQ
     PRINT *, ' RADAR POWER    (W)          : ', RADAR_POWER
     PRINT *, ' ANTENNA GAIN   (dB)         : ', ANTENNA_GAIN
     PRINT *, ' NOISE FIGURE   (dB)         : ', NOISE_FIGURE
     PRINT *, ' TOTAL LOSSES   (dB)         : ', TOTAL_LOSSES
     PRINT *, ' FFT LENGTH                  : ', FFT_LENGTH

     READ(5,*) WEATHER,       WAVE_LENGTH,  RECEIVER_FREQ
    .                RADAR_POWER,  ANTENNA_GAIN, NOISE_FIGURE
    .                TOTAL_LOSSES, FFT_LENGTH

     SETFLAG = 0

  END IF

C------ Compute beamwidths assuming they are equal in azimuth and elevation

  AG = 10.**(0.1*ANTENNA_GAIN)
  AZIM_BEAMWIDTH = SQRT( 27000./AG ) * DEG2RAD
  ELEV_BEAMWIDTH = AZIM_BEAMWIDTH

C------ Compute range resolution

  RANGE_RES = 150.E6 / RECEIVER_FREQ

C------ Compute radial velocity (range rate) resolution (for 20% duty cycle

  TRF = 5.E6 / RECEIVER_FREQ
  PRF = 1.E6 / TRF
  DF  = PRF / FFT_LENGTH

  RRATE_RES = 0.5 * WAVE_LENGTH * DF

C PRINT *, ' DF ', DF, '     DV ', RRATE_RES

C------- Compute maximum radar cross section

  SECTION   = 0.25 * PI * PROJ_DIAMETER**2
  RCSMAX    = 0.4 * PI * SECTION**2 / WAVE_LENGTH**2
  RCSMAXDB  = 10. * ALOG10(RCSMAX)

C------ Compute free space S/N ratio at 1 nautical mile range for maximum R

  STN_0 = 10. * ALOG10(RADAR_POWER) + 2. * ANTENNA_GAIN
       + 20. * ALOG10(WAVE_LENGTH*100.) + RCSMAXDB
```

```
             - 10. * ALOG10(RECEIVER_FREQ*1.E-6) - 60. - NOISE_FIGURE
             - TOTAL_LOSSES + 10. * ALOG10(FFT_LENGTH)

C PRINT *, ' RCSMAXDB ', RCSMAXDB !!
C PRINT *, ' STN_0    ', STN_0    !!

C------ Save values for display

  CALL SAVEINFO( 31
     ., WEATHER,        WAVE_LENGTH,   RECEIVER_FREQ
     ., RADAR_POWER,    ANTENNA_GAIN,  NOISE_FIGURE
     ., TOTAL_LOSSES,   FFT_LENGTH,    ELEV_BEAMWIDTH
     ., AZIM_BEAMWIDTH )

  CALL INFONAMES

C------ Identify frequency band

  IF ( WAVE_LENGTH.LE.LIGHTSPEED/KA_BAND(1) .AND.
     .     WAVE_LENGTH.GT.LIGHTSPEED/KA_BAND(2) ) THEN
     PRINT *, 'KA BAND, wavelength = ', WAVE_LENGTH
  ELSE IF ( WAVE_LENGTH.LE.LIGHTSPEED/K_BAND(1) .AND.
     .     WAVE_LENGTH.GT.LIGHTSPEED/K_BAND(2) ) THEN
     PRINT *, 'K BAND, wavelength = ', WAVE_LENGTH
  ELSE IF ( WAVE_LENGTH.LE.LIGHTSPEED/KU_BAND(1) .AND.
     .     WAVE_LENGTH.GT.LIGHTSPEED/KU_BAND(2) ) THEN
     PRINT *, 'KU BAND, wavelength = ', WAVE_LENGTH
  ELSE IF ( WAVE_LENGTH.LE.LIGHTSPEED/X_BAND(1) .AND.
     .     WAVE_LENGTH.GT.LIGHTSPEED/X_BAND(2) ) THEN
     PRINT *, 'X BAND, wavelength = ', WAVE_LENGTH
  ELSE IF ( WAVE_LENGTH.LE.LIGHTSPEED/Q_BAND(1) .AND.
     .     WAVE_LENGTH.GT.LIGHTSPEED/Q_BAND(2) ) THEN
     PRINT *, 'Q BAND, wavelength = ', WAVE_LENGTH
  ELSE IF ( WAVE_LENGTH.LE.LIGHTSPEED/V_BAND(1) .AND.
     .     WAVE_LENGTH.GT.LIGHTSPEED/V_BAND(2) ) THEN
     PRINT *, 'V BAND, wavelength = ', WAVE_LENGTH
  ELSE IF ( WAVE_LENGTH.LE.LIGHTSPEED/W_BAND(1) .AND.
     .     WAVE_LENGTH.GT.LIGHTSPEED/W_BAND(2) ) THEN
     PRINT *, 'W BAND, wavelength = ', WAVE_LENGTH
  ELSE
     PRINT *, 'FREQUENCY BAND NOT IN DATA BASE FOR'
     PRINT *, 'WAVELENGTH ', WAVE_LENGTH
  END IF

C------ Compute attenuation due to the weather

  IF (WEATHER.EQ.1) THEN
     IF (WAVE_LENGTH.LE.LIGHTSPEED/KA_BAND(1)) THEN
                                                 ! KA BAND AND ABOVE
        ATTENUATION = 2.0
     ELSE IF (WAVE_LENGTH.LE.LIGHTSPEED/K_BAND(1)) THEN
                                                 ! K BAND
        ATTENUATION = 1.0
     ELSE IF (WAVE_LENGTH.LE.LIGHTSPEED/KU_BAND(1)) THEN
```

```
        ATTENUATION = 0.4                                   ! KU BAND
     ELSE                                                   ! X BAND AND BELOW
        ATTENUATION = 0.1
     END IF
  ELSE
     ATTENUATION = 0.0
  END IF

  PRINT *, 'ATTENUATION = ', ATTENUATION

  RETURN
  END
C**********************************************************************

C**********************************************************************
C
  SUBROUTINE RADARMEAS( RADAR_FLAG, ASPECT_ANGLE, HM
     .,              RCS_DB,    STN_DB,        KSIGMA
     .,              RANGE,     RANGE_RATE,    ELEVATION,  AZIMUTH
     .,              RGMEAS,    RRMEAS,        ELMEAS,     AZMEAS
     .,              RGNOISE,   RRNOISE,       ELNOISE,    AZNOISE)
C
C**********************************************************************

  INCLUDE 'RADAR_COM18.FOR'
  REAL ANG, STNF
  REAL RN, HM, SQNINV, STN, GAUSS, RCS_DB, STN_DB, KSIGMA

  REAL
     .  RADAR_FLAG, ASPECT_ANGLE
     ., RANGE,   RANGE_RATE, ELEVATION, AZIMUTH
     ., RGMEAS,  RRMEAS,     ELMEAS,    AZMEAS
     ., RGNOISE, RRNOISE,    AZNOISE,   ELNOISE

C------ Test for RADAR_FLAG

  IF (RADAR_FLAG.EQ.0.0) THEN
     HM      = 1.
     RGNOISE = 0.0
     RRNOISE = 0.0
     ELNOISE = 0.0
     AZNOISE = 0.0
     RGMEAS  = RANGE
     RRMEAS  = RANGE_RATE
     ELMEAS  = ELEVATION
     AZMEAS  = AZIMUTH
     RETURN
  END IF
```

```
C------ Compute the normalized radar cross section, RCS_NORM

  ANG     = PI * PROJ_DIAMETER / WAVE_LENGTH
                 * SIN(ASPECT_ANGLE) + 1.E-5

  RCS_NORM = ABS( SIN(ANG)/ANG ) + 0.01
  RCS_DB   = 10.*ALOG10(RCS_NORM)

C PRINT *, ' RCS_NORM ', RCS_NORM   !!

C------ Compute attenuation due to the weather
C------     Moved to routine RADARSET and
C------     variable ATTENUATION is passed via a common block

C IF (WEATHER.EQ.1) THEN
C    IF (WAVE_LENGTH.LT.1.) THEN
C       ATTENUATION = 2.0
C    ELSE IF (WAVE_LENGTH.LE.1.5) THEN
C       ATTENUATION = 1.0
C    ELSE IF (WAVE_LENGTH.LE.3.) THEN
C       ATTENUATION = 0.4
C    ELSE
C       ATTENUATION = 0.1
C    END IF
C ELSE
C    ATTENUATION = 0.0
C END IF

C------ Compute the actual S/N ratio

  STNF   = STN_0 + 2.*RCS_DB
                 - 40.*ALOG10((RANGE+1.E-6)/NM2M)
  STNDB = STNF - 1.E-3 * ATTENUATION * RANGE
  STN_DB= STNDB

C PRINT *, 'STNDB ' , STNDB

C------ Compute the probability of detection

  IF (STNDB.LE.4.) THEN
     PROB_DETECTION = 0.0
  ELSE IF (STNDB.LE.6.) THEN
     PROB_DETECTION = 0.1
  ELSE IF (STNDB.LE.8.) THEN
     PROB_DETECTION = 0.3
  ELSE IF (STNDB.LE.10.) THEN
     PROB_DETECTION = 0.65
  ELSE IF (STNDB.LE.12.) THEN
```

```
      PROB_DETECTION = 0.85
   ELSE IF (STNDB.LE.14.) THEN
      PROB_DETECTION = 0.92
   ELSE
      PROB_DETECTION = 0.99
   END IF

C------ Set randomly the Hit/Miss flag

   RN = RAN(ISEED)

   IF (PROB_DETECTION.GT.RN) THEN
      HM = 1.0
   ELSE
      HM = 0.001
   END IF

C------ If RADAR_FLAG=1, only HM flag is used (no noise)

   IF (RADAR_FLAG.EQ.1.) THEN
      RGMEAS = RANGE
      RRMEAS = RANGE_RATE
      ELMEAS = ELEVATION
      AZMEAS = AZIMUTH
      RETURN
   END IF

C------ Limit the system S/N ratio to 30 dB (to limit the system accuracy
C------ to a realistic value) for the range rate signal

   STN = 10.**(0.1*MIN(30.,STNDB))
   SQNINV = 0.5 / SQRT(STN)

C------ Compute the error on range rate measurement due to gaussian noise

   RN = RAN(ISEED)                                  ! uniform dist.
   IF (RN.LT.1.E-5) RN = 1.E-5
   GAUSS = SQRT(-2.*LOG(RN)) * COS(TWOPI*RN)        ! gaussian dist.

C  IF (ABS(GAUSS).GT.KSIGMA) HM = 0.
C  GAUSS = SIGN( MIN(KSIGMA.ABS(GAUSS)) , GAUSS )

   RRNOISE = GAUSS * RRATE_RES * SQNINV

C------ Limit the system S/N ratio to 40 dB (to limit the system accuracy
C------ to a realistic value) for the range, elevation angle and azimuth
C------ angle signals
```

```
      IF (STNDB.GT.40.) STNDB = 40.

      STN = 10.**(0.1*STNDB)
      SQNINV = 0.5 / SQRT(STN)

C------ Compute the error on range measurement due to gaussian noise
                                                   ! uniform dist.
      RN = RAN(ISEED)
      IF (RN.LT.1.E-5) RN = 1.E-5
      GAUSS = SQRT(-2.*LOG(RN)) * COS(TWOPI*RN)    ! gaussian dist.

C     IF (ABS(GAUSS).GT.KSIGMA) HM = 0.
C     GAUSS = SIGN( MIN(KSIGMA,ABS(GAUSS)) , GAUSS )

      RGNOISE = GAUSS * RANGE_RES * SQNINV

C------ Compute the error on azimuth measurement due to gaussian noise
                                                   ! uniform dist.
      RN = RAN(ISEED)
      IF (RN.LT.1.E-5) RN = 1.E-5
      GAUSS = SQRT(-2.*LOG(RN)) * COS(TWOPI*RN)    ! gaussian dist.

C     IF (ABS(GAUSS).GT.KSIGMA) HM = 0.
C     GAUSS = SIGN( MIN(KSIGMA,ABS(GAUSS)) , GAUSS )

      AZNOISE = GAUSS * AZIM_BEAMWIDTH * SQNINV

C------ Compute the error on elevation measurement due to gaussian noise
                                                   ! uniform dist.
      RN = RAN(ISEED)
      IF (RN.LT.1.E-5) RN = 1.E-5
      GAUSS = SQRT(-2.*LOG(RN)) * COS(TWOPI*RN)    ! gaussian dist.

C     IF (ABS(GAUSS).GT.KSIGMA) HM = 0.
C     GAUSS = SIGN( MIN(KSIGMA,ABS(GAUSS)) , GAUSS )

      ELNOISE = GAUSS * ELEV_BEAMWIDTH * SQNINV

C------ Set radar measurements

      RGMEAS = RANGE      + RGNOISE
      RRMEAS = RANGE_RATE + RRNOISE
      ELMEAS = ELEVATION  + ELNOISE
      AZMEAS = AZIMUTH    + AZNOISE

      RETURN
```

```
      END
C***********************************************************************

C***********************************************************************
C
      SUBROUTINE INFONAMES
C
C***********************************************************************

      INCLUDE 'COMPLOT'

      INFO(31) = 'WEATHER'
      INFO(32) = 'WAVELENGTH'
      INFO(33) = 'RCVR_FREQ'
      INFO(34) = 'RADARPOWER'
      INFO(35) = 'ANTEN_GAIN'
      INFO(36) = 'NOISE_FIG'
      INFO(37) = 'LOSSES'
      INFO(38) = 'FFT_LENGTH'
      INFO(39) = 'EL_BWIDTH'
      INFO(40) = 'AZ_BWIDTH'

      RETURN
      END
C***********************************************************************

C***********************************************************************
C
      SUBROUTINE LSQ_POLY( X, Y, W, N, P1, C, IER)
C
C This routine computes the coefficients of the polynomial of order
C P1-1 that is the best approximation of the set of data (X,Y) in the
C least-square sense.
C
C Inputs
C ------
C 1) X    : vector of size N containing the independent variable values.
C 2) Y    : vector of size N containing the dependent variable values.
C 3) W    : vector of size N containing the weights for each data point.
C 4) N    : number of data points.
C 5) P1   : number of coefficients (i.e., polynomial order + 1).
C
C Output
C ------
C 1) C    : vector of size P1 containing the polynomial coefficients.
C 2) IER  : IMSL error parameter
C           0   = no error
C           129 = matrix A algorithmically singular
```

```
C            34  = accuracy test failed (number of accurate digits IDGT
C                  not achieved)
C
C Internal variables needed for the IMSL routine LEQT1F
C -----------------------------------------------------------
C The IMSL routine solves the equation A*C=B for C.
C 1) A(10,10)     : matrix of coefficients
C 2) B(10)        : vector of right-hand side values
C 3) WKAREA(10)   : work area
C 4) IDGT         : number of accurate digits for the values of A and B.
C                   (hardcoded as 3)
C
C*******************************************************************

      IMPLICIT NONE

      INTEGER N, P1
      REAL X(N), Y(N), W(N), C(P1)

      REAL A(10,10), B(10)
      INTEGER I, K, L, K1, K2, J
      REAL WKAREA(10), XX
      INTEGER IDGT, IER

C------ Compute the elements of the first column of A

      DO K = 1 , P1
         A(K,1) = 0.0
         DO I = 1 , N
            J = 2*P1-1-K
            IF (J.EQ.0 .AND. X(I).EQ.0.) THEN
               XX = 1.0
            ELSE
               XX = X(I)**J
            END IF
            A(K,1) = A(K,1) + W(I)*XX
         END DO
      END DO

C------ Compute the elements of the last column of A

      DO K = 1 , P1
         A(K,P1) = 0.0
         DO I = 1 , N
            J = P1-K
            IF (J.EQ.0 .AND. X(I).EQ.0.) THEN
               XX = 1.0
            ELSE
               XX = X(I)**J
            END IF
            A(K,P1) = A(K,P1) + W(I)*XX
```

```
      END DO
   END DO
C------ Compute the upper left elements of A

   DO L = 2 , P1-1
   DO K = 1 , P1+1-L
      K1 = K+L-1
      A(K,L) = A(K1,1)
   END DO
   END DO
C------ Compute the lower right elements of A

   DO L = 2 , P1-1
   DO K = P1+2-L , P1
      K2 = K+L-P1
      A(K,L) = A(K2,P1)
   END DO
   END DO
C------ Compute the vector B

   DO K = 1 , P1
      B(K) = 0.0
      DO I = 1 , N
         J = P1-K
         IF (J.EQ.0 .AND. X(I).EQ.0.) THEN
            XX = 1.0
         ELSE
            XX = X(I)**J
         END IF
         B(K) = B(K) + Y(I)*W(I)*XX
      END DO
   END DO
C------ Solve for C:    A*C = B

   IDGT = 3

   CALL LEQT1F( A, 1, P1, 10, B, IDGT, WKAREA, IER)

   DO I = 1 , P1
      C(I) = B(I)
   END DO

   RETURN
   END
C*************************************************************************
```

[redacted] TAR_SIM18.CSL .

```
PROGRAM TRAJECTORY SIMULATION                       TAR_SIM18.CSL  02-MAY-1990
"***********************************************************************"
"                                                                       "
"-  This program solves 6DOF projectile equations + implements control  "
"   laws for identification of METs parameters.  Driven by TAR_MAIN18   "
"   Fortran program.                                                    "
"                                                                       "
"   Modifications:                                                      "
"                                                                       "
"-  Compilation :                                                       "
"        o  Requires the macro file NONE                                "
"                                                                       "
"   Internal Units:    All angles are in radians                        "
"                        All distances in metres                        "
"                        All velocities are in metres per second        "
"                      or rad/sec                                       "
"                                                                       "
"   External Units:    All angles are in degrees                        "
"                        All distances in metres                        "
"                        All velocities are in metres per second        "
"                      or deg/sec                                       "
"                                                                       "
"-  Source :                                                            "
"        1) J. Spacecraft v10, n6 June 1973, pp384-88.                  "
"***********************************************************************"
NOFF-W-IIF,  L ignored
  on output page 34; on input line 28 of page 27 of file "ANALYSIS:[ARMAL.T
""

"***********************************************************************"
"                            Utility macros                             "
"***********************************************************************"
"-----------------------------------------------------------------------"
MACRO FKDA( KDA, MACH, KDAMAC, KDA1, KDA2, KDA3, KDA4, KDA5)            "
"                                                                       "
" Version: 16-AUG-1989                                                  "
" This macro computes the aerodynamic coefficient KDA as a polynomial   "
" function of Mach number.                                              "
"                                                                       "
" Inputs:                                                               "
" - MACH        : Mach number                                           "
" - KDAMAC      : Array of breakpoints for Mach number                  "
" - KDA1-KDA5   : Arrays of polynomial coefficients                     "
"                                                                       "
" Output:                                                               "
" - KDA         : Aerodynamic coefficient
```

```
"
MACRO RELABEL L1, L2, L3, L4, LEND
PROCEDURAL( KDA = MACH )

       IF ( MACH .GT. KDAMAC(1) )  GOTO L1
          KDA = KDA1(1)
          GOTO LEND
       L1..CONTINUE
       IF ( MACH .GT. KDAMAC(2) )  GOTO L2
          KDA = KDA2(1) + MACH * ( KDA2(2) + MACH * ( KDA2(3) ...
                        + MACH * ( KDA2(4) + MACH * KDA2(5) ) ) )
          GOTO LEND
       L2..CONTINUE
       IF ( MACH .GT. KDAMAC(3) )  GOTO L3
          KDA = KDA3(1) + MACH * ( KDA3(2) + MACH * ( KDA3(3) ...
                        + MACH * ( KDA3(4) + MACH * KDA3(5) ) ) )
          GOTO LEND
       L3..CONTINUE
       IF ( MACH .GT. KDAMAC(4) )  GOTO L4
          KDA = KDA4(1) + MACH * ( KDA4(2) + MACH * ( KDA4(3) ...
                        + MACH * ( KDA4(4) + MACH * KDA4(5) ) ) )
          GOTO LEND
       L4..CONTINUE
          KDA = KDA5(1) + KDA5(2)*MACH
       LEND..CONTINUE

END $ " of PROCEDURAL "
MACRO END
"-------------------------------------------------------------------"
JNOFF-W-IIF, ^L ignored
   on output page 35; on input line 78 of page 27 of file "ANALYSIS:[ARMAL.T
""

                                                                    "
"-------------------------------------------------------------------
MACRO FKD0( KD0, MACH, KD0MAC, KD01, KD02, KD03, KD04, KD05, KD06, KD07)
"                                                                   "
" Version: 16-AUG-1989                                              "
" This macro computes the aerodynamic coefficient KD0 as a polynomial "
" function of Mach number.                                          "
"                                                                   "
" Inputs:                                                           "
" - MACH          : Mach number                                     "
" - KD0MAC        : Array of breakpoints for Mach number            "
" - KD01-KD07     : Arrays of polynomial coefficients               "
"                                                                   "
" Output:                                                           "
" - KD0           : Aerodynamic coefficient                         "
"
MACRO RELABEL L1, L2, L3, L4, L5, L6, LEND
PROCEDURAL( KD0 = MACH )

       IF ( MACH .GT. KD0MAC(1) )  GOTO L1
          KD0 = KD01(1)
```

```
        GOTO LEND
      L1..CONTINUE
      IF ( MACH .GT. KD0MAC(2) )  GOTO L2
        KD0 = KD02(1) + MACH * ( KD02(2) + MACH * ( KD02(3) ...
                      + MACH * ( KD02(4) + MACH * KD02(5) ) ) )
        GOTO LEND
      L2..CONTINUE
      IF ( MACH .GT. KD0MAC(3) )  GOTO L3
        KD0 = KD03(1) + MACH * ( KD03(2) + MACH * ( KD03(3) ...
                      + MACH * ( KD03(4) + MACH * KD03(5) ) ) )
        GOTO LEND
      L3..CONTINUE
      IF ( MACH .GT. KD0MAC(4) )  GOTO L4
        KD0 = KD04(1) + MACH * ( KD04(2) + MACH * ( KD04(3) ...
                      + MACH * ( KD04(4) + MACH * KD04(5) ) ) )
        GOTO LEND
      L4..CONTINUE
      IF ( MACH .GT. KD0MAC(5) )  GOTO L5
        KD0 = KD05(1) + MACH * ( KD05(2) + MACH * ( KD05(3) ...
                      + MACH * ( KD05(4) + MACH * KD05(5) ) ) )
        GOTO LEND
      L5..CONTINUE
      IF ( MACH .GT. KD0MAC(6) )  GOTO L6
        KD0 = KD06(1) + MACH * ( KD06(2) + MACH * ( KD06(3) ...
                      + MACH * ( KD06(4) + MACH * KD06(5) ) ) )
        GOTO LEND
      L6..CONTINUE
        KD0 = KD07(1) + MACH * ( KD07(2) + MACH * ( KD07(3) ...
                      + MACH * ( KD07(4) + MACH * KD07(5) ) ) )
      LEND..CONTINUE
  END $ " of PROCEDURAL "
  MACRO END
"-----------------------------------------------------------------"
INOFF-W-IIF, `L ignored
  on output page 36; on input line 135 of page 27 of file "ANALYSIS:[ARMAL.
""

"-----------------------------------------------------------------"
MACRO FKL0( KL0, MACH, KL0MAC, KL01, KL02, KL03, KL04, KL05)       "
"                                                                  "
" Version: 16-AUG-1989                                             "
" This macro computes the aerodynamic coefficient KL0 as a polynomial "
" function of Mach number.                                         "
"                                                                  "
" Inputs:                                                          "
" - MACH          : Mach number                                    "
" - KL0MAC        : Array of breakpoints for Mach number           "
" - KL01-KL05     : Arrays of polynomial coefficients              "
"                                                                  "
" Output:                                                          "
" - KL0           : Aerodynamic coefficient                        "
"
```

```
MACRO RELABEL L1, L2, L3, L4, LEND
PROCEDURAL( KL0 = MACH )

        IF ( MACH .GT. KL0MAC(1) )  GOTO L1
           KL0 = KL01(1) + KL01(2)*MACH
           GOTO LEND
        L1..CONTINUE
        IF ( MACH .GT. KL0MAC(2) )  GOTO L2
           KL0 = KL02(1) + MACH * ( KL02(2) + MACH * ( KL02(3) ...
                         + MACH * ( KL02(4) + MACH * KL02(5) ) ) )
           GOTO LEND
        L2..CONTINUE
        IF ( MACH .GT. KL0MAC(3) )  GOTO L3
           KL0 = KL03(1) + MACH * ( KL03(2) + MACH * ( KL03(3) ...
                         + MACH * ( KL03(4) + MACH * KL03(5) ) ) )
           GOTO LEND
        L3..CONTINUE
        IF ( MACH .GT. KL0MAC(4) )  GOTO L4
           KL0 = KL04(1) + MACH * ( KL04(2) + MACH * ( KL04(3) ...
                         + MACH * ( KL04(4) + MACH * KL04(5) ) ) )
           GOTO LEND
        L4..CONTINUE
           KL0 = KL05(1) + KL05(2)*MACH
        LEND..CONTINUE

END $ " of PROCEDURAL "
MACRO END
"-------------------------------------------------------------------"
'NOFF-W-IIF, ^L ignored
   on output page 37; on input line 181 of page 27 of file "ANALYSIS:[ARMAL.
""

"-------------------------------------------------------------------"
MACRO FKM( KM, MACH, KMMAC, KM1, KM2, KM3, KM4, KM5, KM6, KM7, KM8, KM9)
"                                                                    "
" Version: 16-AUG-1989                                               "
" This macro computes the aerodynamic coefficient KM as a polynomial "
" function of Mach number.                                           "
"                                                                    "
" Inputs:                                                            "
" - MACH          : Mach number                                      "
" - KMMAC         : Array of breakpoints for Mach number             "
" - KM1-KM9       : Arrays of polynomial coefficients                "
"                                                                    "
" Output:                                                            "
" - KM            : Aerodynamic coefficient                          "
"
MACRO RELABEL L1, L2, L3, L4, L5, L6, L7, L8, LEND
PROCEDURAL( KM = MACH )

        IF ( MACH .GT. KMMAC(1) )  GOTO L1
           KM = KM1(1)
           GOTO LEND
```

```
      L1..CONTINUE
      IF ( MACH .GT. KMMAC(2) )  GOTO L2
         KM = KM2(1) + MACH * ( KM2(2) + MACH * ( KM2(3) ...
                     + MACH * ( KM2(4) + MACH * KM2(5) ) ) )
         GOTO LEND
      L2..CONTINUE
      IF ( MACH .GT. KMMAC(3) )  GOTO L3
         KM = KM3(1) + MACH * ( KM3(2) + MACH * ( KM3(3) ...
                     + MACH * ( KM3(4) + MACH * KM3(5) ) ) )
         GOTO LEND
      L3..CONTINUE
      IF ( MACH .GT. KMMAC(4) )  GOTO L4
         KM = KM4(1) + MACH * ( KM4(2) + MACH * ( KM4(3) ...
                     + MACH * ( KM4(4) + MACH * KM4(5) ) ) )
         GOTO LEND
      L4..CONTINUE
      IF ( MACH .GT. KMMAC(5) )  GOTO L5
         KM = KM5(1) + MACH * ( KM5(2) + MACH * ( KM5(3) ...
                     + MACH * ( KM5(4) + MACH * KM5(5) ) ) )
         GOTO LEND
      L5..CONTINUE
      IF ( MACH .GT. KMMAC(6) )  GOTO L6
         KM = KM6(1) + MACH * ( KM6(2) + MACH * ( KM6(3) ...
                     + MACH * ( KM6(4) + MACH * KM6(5) ) ) )
         GOTO LEND
      L6..CONTINUE
      IF ( MACH .GT. KMMAC(7) )  GOTO L7
         KM = KM7(1) + MACH * ( KM7(2) + MACH * ( KM7(3) ...
                     + MACH * ( KM7(4) + MACH * KM7(5) ) ) )
         GOTO LEND
      L7..CONTINUE
      IF ( MACH .GT. KMMAC(8) )  GOTO L8
         KM = KM8(1) + MACH * ( KM8(2) + MACH * ( KM8(3) ...
                     + MACH * ( KM8(4) + MACH * KM8(5) ) ) )
         GOTO LEND
      L8..CONTINUE
         KM = KM9(1) + MACH * ( KM9(2) + MACH * ( KM9(3) ...
                     + MACH * ( KM9(4) + MACH * KM9(5) ) ) )
      LEND..CONTINUE

   END S " of PROCEDURAL "
   MACRO END
   "-----------------------------------------------------------------------"
JNOFF-W-IIF, ^L ignored
    on output page 38; on input line 248 of page 27 of file "ANALYSIS:[ARMAL.
   ""

   "-----------------------------------------------------------------------"
   MACRO FKA( KA, MACH, KAMAC, KA1, KA2)                                  "
   "                                                                      "
   " Version: 16-AUG-1989                                                 "
   " This macro computes the aerodynamic coefficient KA as a polynomial   "
   " function of Mach number.
```

```
"
" Inputs:
" - MACH          : Mach number
" - KAMAC         : Array of breakpoints for Mach number
" - KA1-KA9       : Arrays of polynomial coefficients
"
" Output:         : Aerodynamic coefficient
" - KA
"
MACRO RELABEL L1, LEND
PROCEDURAL( KA = MACH )

      IF ( MACH .GT. KAMAC(1) )   GOTO L1
         KA = KA1(1) + MACH * ( KA1(2) + MACH * ( KA1(3) ...
                     + MACH * ( KA1(4) + MACH * KA1(5) ) ) )

   GOTO LEND
      L1..CONTINUE
         KA = KA2(1) + MACH * ( KA2(2) + MACH * ( KA2(3) ...
                     + MACH * ( KA2(4) + MACH * KA2(5) ) ) )

      LEND..CONTINUE

END $ " of PROCEDURAL "
MACRO END
" -----------------------------------------------------------------"
NOFF-W-IIF, ^L ignored
   on output page 39; on input line 281 of page 27 of file "ANALYSIS:[ARMAL.
""

"****************************************************************"
"                                                                "
"*************************** ACSL TABLES ************************"
"                                                                "
"****************************************************************"

"----- Earth coordinates of wind velocity relative to the Earth (m/sec)"

     TABLE VWXTAB, 1, 20 /                                    ...
     0.    , 1000.  , 2000.  , 3000.  , 4000.  ,  ...
     5000. , 6000.  , 7000.  , 8000.  , 9000.  ,  ...
     1.0E4 , 1.1E4  , 1.2E4  , 1.3E4  , 1.4E4  ,  ...
     1.5E4 , 1.6E4  , 1.7E4  , 1.8E4  , 1.9E4  ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   /

     TABLE VWYTAB, 1, 20 /                                    ...
     0.    , 1000.  , 2000.  , 3000.  , 4000.  ,  ...
     5000. , 6000.  , 7000.  , 8000.  , 9000.  ,  ...
     1.0E4 , 1.1E4  , 1.2E4  , 1.3E4  , 1.4E4  ,  ...
     1.5E4 , 1.6E4  , 1.7E4  , 1.8E4  , 1.9E4  ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   ,  ...
     7.07  , 7.07   , 7.07   , 7.07   , 7.07   /
```

```
"----- Air density (kg/m**3) "

       TABLE RHOTAB, 1, 20 /                              ...
       0.     , 1000. , 2000. , 3000. , 4000. ,           ...
       5000.  , 6000. , 7000. , 8000. , 9000. ,           ...
       1.0E4  , 1.1E4 , 1.2E4 , 1.3E4 , 1.4E4 ,           ...
       1.5E4  , 1.6E4 , 1.7E4 , 1.8E4 , 1.9E4 ,           ...
       1.2245, 1.1095, 1.0051, 0.9082, 0.8184,            ...
       0.7357, 0.6559, 0.5872, 0.5218, 0.4656,            ...
       0.4112, 0.3616, 0.3118, 0.2629, 0.2259,            ...
       0.1929, 0.1640, 0.1423, 0.1206, 0.1029/

"----- Temperature (degK) "

       TABLE TMPTAB, 1, 20 /                              ...
       0.     , 1000. , 2000. , 3000. , 4000. ,           ...
       5000.  , 6000. , 7000. , 8000. , 9000. ,           ...
       1.0E4  , 1.1E4 , 1.2E4 , 1.3E4 , 1.4E4 ,           ...
       1.5E4  , 1.6E4 , 1.7E4 , 1.8E4 , 1.9E4 ,           ...
       288.20, 281.69, 275.20, 268.70, 262.20,            ...
       255.70, 249.10, 242.63, 236.35, 229.70,            ...
       223.25, 216.75, 215.05, 216.65, 216.70,            ...
       216.70, 216.70, 216.70, 216.70, 216.70/

"----- Correction for wind coordinates and air density "

       TABLE VWXCOR, 1, 1600 / 0., 1599*1.E6, 1600*0. /
       TABLE VWYCOR, 1, 1600 / 0., 1599*1.E6, 1600*0. /
       TABLE RHOCOR, 1, 1600 / 0., 1599*1.E6, 1600*0. /

INOFF-W-IIF, ^L ignored
   on output page 40; on input line 340 of page 27 of file "ANALYSIS:[ARMAL.
""

"*******************************************************************"
"          Communication interval and miscellaneous constants        "
"*******************************************************************"

       CINTERVAL      CINT = 0.1

       CONSTANT       DTORAD = 57.295779          $ " BRL CONSTANT  C1 "
       CONSTANT       G      = 9.80665
       CONSTANT       PI     = 3.1415926

       CONSTANT DUM = 0.0
       CONSTANT LFTFAC = 1.  $ "0.9627 BRL multiplier on KL0 and KLA "
       CONSTANT CLPFAC = 1.0 , CX0FAC = 1.0 , CX2FAC = 1.0

INOFF-W-IIF, ^L ignored
   on output page 40; on input line 357 of page 27 of file "ANALYSIS:[ARMAL.
""

"*******************************************************************"
```

```
INITIAL
"*****************************************************************"

"----- BRL Aero data from BRL FCI-155 "
  ARRAY KDA1(1), KDA2(5), KDA3(5), KDA4(5), KDA5(2), KDAMAC(4)
  ARRAY KD01(1), KD02(5), KD03(5), KD04(5), KD05(5), KD06(5)
  ARRAY KD07(5), KD0MAC(6)
  ARRAY KL01(2), KL02(5), KL03(5), KL04(5), KL05(2), KL0MAC(4)
  ARRAY KM1(1),  KM2(5),  KM3(5),  KM4(5),  KM5(5),  KM6(5)
  ARRAY KM7(5),  KM8(5),  KM9(5),  KMMAC(8)
  ARRAY KA1(5),  KA2(5),  KAMAC(1)

"- Define constants in Aero Data Arrays "

  CONSTANT  KDA1   = 2.3
  CONSTANT  KDA2   = -38.981984   , 129.07274   , -187.64977   , ...
                     108.48648    , -18.128487
  CONSTANT  KDA3   = 189.37350    , -694.01933  , 949.29028    , ...
                     -568.33625   , 126.47310
  CONSTANT  KDA4   = -37.317582   , 94.483221   , -81.427874   , ...
                     31.613187    , -4.6953080
  CONSTANT  KDA5   = 5.6409091    , -0.90909091
  CONSTANT  KDAMAC= 0.80          , 0.97        , 1.19         , ...
                     1.80
  CONSTANT  KD01   = 0.05
  CONSTANT  KD02   = 106.55819    , -495.42480  , 864.31252    , ...
                     -670.28411   , 194.96965
  CONSTANT  KD03   = -621.41655   , 2716.0843   , -4439.6671   , ...
                     3216.5548    , -871.42812
  CONSTANT  KD04   = 103.02763    , -315.74748  , 321.87224    , ...
                     -109.02406   , 0.0
  CONSTANT  KD05   = -1580.9899   , 5951.9060   , -8402.0232   , ...
                     5271.5295    , -1240.2931
  CONSTANT  KD06   = -5.2380076   , 16.492312   , -18.761161   , ...
                     9.4212207    , -1.7685151
  CONSTANT  KD07   = 0.20694309   , -.0040499634, -.071698139  , ...
                     0.034380058  , -.0046420421
  CONSTANT  KD0MAC= 0.84          , 0.915       , 0.99         , ...
                     1.035        , 1.08        , 1.38
  CONSTANT  KL01   = 0.55         , 0.057692308
  CONSTANT  KL02   = 5.2834534    , -28.181146  , 63.189386    , ...
                     -62.964179   , 23.626028
  CONSTANT  KL03   = 157.96430    , -669.99668  , 1064.1109    , ...
                     -747.59628   , 196.31506
  CONSTANT  KL04   = -30.483617   , 105.03552   , -132.91606   , ...
                     75.152710    , -15.991247
  CONSTANT  KL05   = 0.71218182   , 0.12727273
  CONSTANT  KL0MAC= 0.60          , 0.88        , 1.00         , ...
                     1.23
  CONSTANT  KM1    = 1.28
  CONSTANT  KM2    = 1.7205997    , -3.2865187  , 8.9650248    , ...
```

```
                   -10.862163     , 5.2689872
CONSTANT  KM3    = 546.68334      , -2628.0014   , 4750.3697    , ...
                   -3818.3687     , 1152.1293
CONSTANT  KM4    = 54.348067      , -175.99694   , 192.95224    , ...
                   -69.482520     , 0.0
CONSTANT  KM5    = 7878.3217      , -25448.989   , 27401.966    , ...
                   -9832.7886     , 0.0
CONSTANT  KM6    = 4584.2952      , -18887.324   , 29191.895    , ...
                   -20049.737     , 5162.3900
CONSTANT  KM7    = 1811.4857      , -6837.4301   , 9583.8249    , ...
                   -5972.3512     , 1395.9822
CONSTANT  KM8    = 20.761223      , -56.326884   , 61.499434    , ...
                   -29.895752     , 5.4463004
CONSTANT  KM9    = 2.3778853      , -2.2737848   , 1.8901715    , ...
                   -0.69989459    , 0.090931133
CONSTANT  KMMAC  = 0.39           , 0.81         , 0.86         , ...
                   0.939          , 0.946        , 1.02         , ...
                   1.06           , 1.50
CONSTANT  KA1    = 0.007          , -.0026504608,-.00090103102, ...
                   0.0025286890   , -.0011479416
CONSTANT  KA2    = 0.006724987    , -.0024994776, .00071838136, ...
                   -.00012021482, -.00000806355
CONSTANT  KAMAC  = 0.90

"--------------------------------------------------------------------"
LOGICAL    INTERA, COSTLM
CONSTANT   INTERA = .FALSE., COSTLM = .FALSE.
ARRAY      XNOM(1600),    YNOM(1600),    ZNOM(1600)
ARRAY      VXNOM(1600),   VYNOM(1600),   VZNOM(1600)
ARRAY      RHONOM(1600),  VWXNOM(1600),  VWYNOM(1600)
ARRAY      RNGNOM(1600),  RRTNOM(1600),  TIMNOM(1600)
ARRAY      AZMNOM(1600),  ELVNOM(1600)
ARRAY      AZDNOM(1600),  ELDNOM(1600)
ARRAY      VWXPN(1600),   VWYPN(1600)
ARRAY      RGMEAS(1600),  RRMEAS(1600)
ARRAY      AZMEAS(1600),  ELMEAS(1600)
ARRAY      HMFLAG(1600),  MEASW(1600)
CONSTANT   XNOM   = 1600*0., YNOM   = 1600*0., ZNOM   = 1600*0.
CONSTANT   VXNOM  = 1600*0., VYNOM  = 1600*0., VZNOM  = 1600*0.
CONSTANT   RHONOM = 1600*0., VWXNOM = 1600*0., VWYNOM = 1600*0.
CONSTANT   RNGNOM = 1600*0., RRTNOM = 1600*0., TIMNOM = 1600*0.
CONSTANT   AZMNOM = 1600*0., ELVNOM = 1600*0.
CONSTANT   AZDNOM = 1600*0., ELDNOM = 1600*0.
CONSTANT   RGMEAS = 1600*0., RRMEAS = 1600*0.
CONSTANT   AZMEAS = 1600*0., ELMEAS = 1600*0.
CONSTANT   HMFLAG = 1600*0., MEASW  = 1600*0.
CONSTANT   COSTTH = 0.9,     PTOL   = 0.1,  BTOL   = 0.9
CONSTANT   COSTI  = 1.E20,  TFINAL = 90.0
CONSTANT   LVX = 50, LVY = 50, LVZ = 50

INTEGER    NWEIGH, NMEAS
```

```
CONSTANT      NWEIGH = 360, MXWDSL = 0.02, DBFLAG = 1.
CONSTANT      NMEAS  = 230

ARRAY         COSTVX(40), COSTVY(40), COSTVZ(40), ALTLAY(20)
INTEGER       NCOST(40)
INTEGER       ILAYER, STLAY, PSTLAY, KOUNT, MAXLAY, NLAYER
INTEGER       RUNFLG
CONSTANT      RUNFLG = 1, NLAYER = 1, LAYER = 1000.
CONSTANT      COSTVX = 40*0, COSTVY = 40*0, COSTVZ = 40*0
CONSTANT      NCOST  = 40*0
CONSTANT      ALTLAY = 0.0   , 1.0E3, 2.0E3, 3.0E3, 4.0E3, ...
                       5.0E3, 6.0E3, 7.0E3, 8.0E3, 9.0E3, ...
                       1.0E4, 1.1E4, 1.2E4, 1.3E4, 1.4E4, ...
                       1.5E4, 1.6E4, 1.7E4, 1.8E4, 1.9E4
CONSTANT      TCHNG0 = 0.5

ARRAY         RHOLIM(20,2), VWXLIM(20,2), VWYLIM(20,2)
CONSTANT      RHOLIM = ...
              1.4245, 1.40  , 1.20  , 1.00  , 0.90  , ...
              0.90  , 0.80  , 0.80  , 0.60  , 0.50  , ...
              0.45  , 0.45  , 0.45  , 0.45  , 0.45  , ...
              0.45  , 0.45  , 0.45  , 0.45  , 0.45  , ...
              1.0245, 1.00  , 0.90  , 0.70  , 0.60  , ...
              0.60  , 0.60  , 0.50  , 0.35  , 0.30  , ...
              0.25  , 0.00  , 0.00  , 0.00  , 0.00  , ...
              0.00  , 0.00  , 0.00  , 0.00  , 0.00
CONSTANT      VWXLIM = 20*20, 20*-20
CONSTANT      VWYLIM = 20*20, 20*-20
"---------------------------------------------------------------------"
      IF (T.EQ.0.0) ALT = ALTIC
      STLAY  = INT( ALT/LAYER ) + 1
      OLDALT = ALT
      MAXLAY = STLAY
      JLAYER = STLAY
      COUNT  = COUNT - 1
      KOUNT  = 0
"---------------------------------------------------------------------"

      IF (T.NE.0.0) GO TO 99997

"----- Constants "

      A8OPI    = 8.0 / PI
      A16OPI   = 16.0 / PI

"------ Set seed number "

      INTEGER RNSEED, GSEED
      CONSTANT RNSEED = 2234567
      GSEED = RNSEED
      GAUSI(GSEED)
```

```
"----- Plot initialization "

       COUNT = 0

"----- Descent flag at T=0 is false "

       DSCNT0 = .FALSE.

"----- Initial conditions for integrators "

       " Using BRL FCT Data   Trajectory 2 :                                  "
       "  Charge 08 , Vmuzzle = 690.8
       "  Elevation = 53.44 deg=950 MILS, SPIN = 220 REV/SEC=79200 DPS "
       "                                         300 REV/SEC=108000 DPS"

       CONSTANT ELVDIC =   0.0 , SPIN  =  79200., YAWD  = 0.0
       CONSTANT ELVIC  =  53.44, ROLL  =    0.0 , YAW   = 0.0
       CONSTANT UIC    = 690.8, VIC   =    0.0 , WIC   = 0.0
       CONSTANT XEIC   =   0.0 , YEIC  =    0.0 , ALTIC = 0.0

       THEIC  = -ELVIC / DTORAD
       PHIIC  =  ROLL  / DTORAD
       PSIIC  =  YAW   / DTORAD

       THDTIC = -ELVDIC / DTORAD
       PHDTIC =  SPIN   / DTORAD
       PSDTIC =  YAWD   / DTORAD

"----- Projectile characteristics "

       CONSTANT  MASS = 43.09124   $  " Mass  ( 95 lb )          : kg       "
       CONSTANT  IX   = 0.1477     $  " Inertia about X-axis     : kg-m**2  "
       CONSTANT  IY   = 1.8009     $  " Inertia about X-axis     : kg-m**2  "
       CONSTANT  L    = .155       $  " Diameter                 : m        "

       A  = PI*L*L*0.25            $  " Section area             : m**2     "

"----- Constants "

       TWOPI =  2. * PI
       L2    =  L * 0.5
       AoMASS=  A / MASS
       IXoIY =  IX / IY
       ALoIX =  A * L / IX
       ALoIY =  A * L / IY
       IXIX  =  IX*IX
       IY2   =  2.*IY
       IY4   =  4.*IY
       ALFMAX= 0.0

"----- Initialize wind velocity and angle of attack "
```

```
VWEEX   =  VWXTAB(ALTIC)
VWEEY   =  VWYTAB(ALTIC)

SINTHE  =  SIN(THEIC)
COSTHE  =  COS(THEIC)
SINPSI  =  SIN(PSIIC)
COSPSI  =  COS(PSIIC)

UAEB    =  VWEEX * COSTHE*COSPSI + VWEEY * COSTHE*SINPSI
VAEB    = -VWEEX * SINPSI        + VWEEY * COSPSI
WAEB    =  VWEEX * SINTHE*COSPSI + VWEEY * SINTHE*SINPSI

UW      =  UIC - UAEB
VW      =  VIC - VAEB
WW      =  WIC - WAEB
VTW     =  SQRT(UW*UW+VW*VW+WW*WW)

ALFA    =  ACOS(UW/VTW)
EPS     =  SIN(ALFA)
EPSSQ   =  EPS*EPS
VWoVTW  =  VW/VTW
WWoVTW  =  WW/VTW
RHO     =  KRHO * RHOTAB(ALTIC)
QBAR    =  0.5*RHO*VTW*VTW
TEMPK   =  KTEMP * TMPTAB(ALTIC)
VSOND   =  C3 * SQRT( TEMPK )
MACH    =  VTW / VSOND

UPEE    =  UIC*COSTHE*COSPSI - VIC*SINPSI + WIC*SINTHE*COSPSI
VPEE    =  UIC*COSTHE*SINPSI + VIC*COSPSI + WIC*SINTHE*SINPSI
WPEE    = -UIC*SINTHE                     + WIC*COSTHE

AZIM    =  PSIIC
ELEV    = -THEIC
XLOSE   =  COS(ELEV)*COS(AZIM)
YLOSE   =  COS(ELEV)*SIN(AZIM)
ZLOSE   =  SIN(ELEV)
RRT     =  UPEE*XLOSE + VPEE*YLOSE + WPEE*ZLOSE
RNG     =  0.0

DVZF1   = 0.0
DVXF1   = 0.0
DVYF1   = 0.0

"----- Set radar parameters "
"      . SETFLG=1:  the routine RADARSET will allow the user to modify "
"                   the values of the radar parameters.                "
"      . RADFLG=0:  the routine RADARMEAS will set HITMSS to 1, xxNOIS "
"                   to 0 and xxRDAR to nominal values. The feedback    "
"                   signals are DX, DY and DZ.                         "
"      . RADFLG=1:  the routine RADARMEAS will set HITMSS based on the "
```

```
"                   radar equation, xxNOIS to 0 and xxRDAR to nominal  "
"                   values.  The feedback signals are DX, DY and DZ.   "
"   . RADFLG=2:     the routine RADARMEAS will set HITMSS based on the "
"                   noise threshold KSIGMA.  The feedback signals are  "
"                   XERR, YERR and ZERR.                               "
"   . KSIGMA:       noise threshold (# of sigmas) for hit/miss decision"

      INTEGER SETFLG
      CONSTANT SETFLG = 1, HITMSS = 1., RADFLG = 1.
      CONSTANT KSIGMA = 2.

      IF (RUNFLG.EQ.1) CALL RADARSET( L, RNSEED, SETFLG)

      RGNOIS = 0.0 $ RRNOIS = 0.0 $ ELNOIS = 0.0 $ AZNOIS = 0.0
      RGRDAR = 0.0 $ RRRDAR = 0.0 $ ELRDAR = 0.0 $ AZRDAR = 0.0
      RCSDB  = 0.0 $ STNDB  = 0.0

      ADMS = 0.0
      EDMS = 0.0

"----- Backward rectangular integration of range rate "

      INTGRR = 0.0

      INTEGER NAPEX
      NAPEX = 5555

INOFF-W-IIF, ^L ignored
    on output page 46; on input line 648 of page 27 of file "ANALYSIS:[ARMAL.
   END $ " of INITIAL "

"**********************************************************************"
                              DYNAMIC
"**********************************************************************"

                       "**************************"
                            DERIVATIVE SLOW
                       "**************************"

"----- Simulation control parameters "

      NSTEPS        NSTP1  = 1
      ALGORITHM     IALG1  = 3
      MAXTERVAL     MAXT1  = 0.01
      MINTERVAL     MINT1  = 0.01

"----- Simulation termination conditions "

      LOGICAL    OVFLOW

      "- Overflow prediction "
```

```
OVFLOW = (ABS(UDOT).GT.UDOT99) .OR. (ABS(VDOT).GT.VDOT99) ...
         .OR. (ABS(WDOT).GT.WDOT99)

"----- Atmospheric model, incl inputs for METs closed loop estmation"

PROCEDURAL (DRHOFB, DVWXFB, DVWYFB = )

IF (.NOT.CLMET) GO TO NOCL

   CONSTANT KZER = .01, KVZER = .2, KAZER = 0. $ "RHO estim loop"
   CONSTANT KRGER = 0., KRRER = 0.
   " using Z-error or Range-error"
   LOGICAL RBOUND $ CONSTANT RBOUND   = .FALSE.
   DRFBMN  = RSW( RBOUND, -KRHO*RHOTAB(ALT)-RHOCOR(ALT), -1.E30)
   DRHOFB  = AMAX1( DRFBMN, KZER*DZF + KVZER*DVZF )

   CONSTANT KXER =.05, KVXER = 10, KAXER = 0.  $ "VWX estim loop"
   DVWXFB  =-KXER*DXF - KVXER*DVXF

   CONSTANT KYER =.05, KVYER = 10, KAYER = 0.  $ "VWY estim loop"
   DVWYFB  =-KYER*DYF - KVYER*DVYF

NOCL..CONTINUE

END $ "OF PROCEDURAL"

CONSTANT KRHO  = 1., KVWX = 1., KVWY = 1., KTEMP = 1.
CONSTANT VWEEZ = 0.

RHO   = KRHO  * RHOTAB( ALT )       + ...
        RSW(CLMET, DRHOFB, 0.0) + RHOCOR( ALT )
VWEEX = KVWX  * VWXTAB( ALT )       + ...
        RSW(CLMET, DVWXFB, 0.0) + VWXCOR( ALT )
VWEEY = KVWY  * VWYTAB( ALT )       + ...
        RSW(CLMET, DVWYFB, 0.0) + VWYCOR( ALT )
TEMPK = KTEMP * TMPTAB( ALT )

"----- Aerodynamic coefficients "

PROCEDURAL

"- Speed of sound and Mach number "

CONSTANT C3 = 20.0468

VSOND = C3 * SQRT ( TEMPK )
MACH  = VTW / VSOND

"- Spin deceleration coefficient -"

FKA( KA, MACH, KAMAC, KA1, KA2)
```

```
CLP  = - KA * A16OPI * CLPFAC

"- Pitching moment coefficient -"

FKM( KM, MACH, KMMAC, KM1, KM2, KM3, KM4, KM5, KM6, KM7, KM8,KM9)
CMA   =  KM * A8OPI

"- Damping in pitch moment coefficient "

CONSTANT CMQ  = 0.0

"- Magnus moment coefficient "

CONSTANT CNPA = 0.0

"- Axial force coefficient -"

FKD0( KD0, MACH, KD0MAC, KD01, KD02, KD03, KD04,KD05,KD06,KD07)
FKDA( KDA, MACH, KDAMAC, KDA1, KDA2, KDA3, KDA4, KDA5)
CX0 = KD0 * A8OPI * CX0FAC
CX2 = KDA * A8OPI * CX2FAC
CX  = CX0 + CX2 * EPSSQ

"- Normal force coefficient -"

CONSTANT KLA  = 5.0

FKL0( KL0, MACH, KL0MAC, KL01, KL02, KL03, KL04, KL05)
N0  = KL0 * A8OPI
N3  = KLA * A8OPI
CNA = ( N0 +  N3 * EPSSQ ) * LFTFAC

"- Magnus force coefficient -"

CONSTANT KF   = 0.13

CYPA =   KF * A16OPI

END $ " of PROCEDURAL "

"----- Precession/nutation frequencies "

MU      = QBAR*A*L*CMA
DISC    = IXIX*P2 - IY4*MU

IXP     = IX*P
SQdisc  = SQRT(ABS(DISC))

PROCEDURAL

  IF (DISC.LT.0.) GO TO LL1
    OMEGA1 = (IXP + SQdisc) / IY2
```

```
        OMEGA2 = (IXP - SQdisc) / IY2
        GO TO LL2
     LL1..CONTINUE
        OMEGA1 = 0.0
        OMEGA1 = 0.0
     LL2..CONTINUE

    END $ " of PROCEDURAL"

"----- Gyroscopic stability factor "

    PROCEDURAL
    IF (MU.EQ.0.0) SG = 1000.
    IF (MU.NE.0.0) SG = IXIX*P2 / IY4 / MU
    END $ " of PROCEDURAL"

"----- Filtering velocity error for closed loop MET estimates"

    CONSTANT TAURR = 1.
    RRERRF = REALPL( TAURR , RRERR , 0. )

    CONSTANT TAUX = 0.1, TAUY = 0.1, TAUZ = 0.1

    DXF1 = RSW( RADFLG.EQ.2 , XERR , DX )
    DYF1 = RSW( RADFLG.EQ.2 , YERR , DY )
    DZF1 = RSW( RADFLG.EQ.2 , ZERR , DZ )

    DXF = REALPL( TAUX , DXF1 , 0. )
    DYF = REALPL( TAUY , DYF1 , 0. )
    DZF = REALPL( TAUZ , DZF1 , 0. )

    CONSTANT TAUVX = 2., TAUVY = 2., TAUVZ = 1.

    DVXF1 = RSW( RADFLG.EQ.2 , VXERR , DVX )
    DVYF1 = RSW( RADFLG.EQ.2 , VYERR , DVY )
    DVZF1 = RSW( RADFLG.EQ.2 , VZERR , DVZ )

    DVXF = REALPL( TAUVX , DVXF1 , 0. )
    DVYF = REALPL( TAUVY , DVYF1 , 0. )
    DVZF = REALPL( TAUVZ , DVZF1 , 0. )

NOFF-W-IIF, ^L ignored
    on output page 49; on input line 818 of page 27 of file "ANALYSIS:[ARMAL.
  END $ " of DERIVATIVE SLOW "


                "*************************"
                     DERIVATIVE FAST
                "*************************"


"----- Simulation control parameters "
```

```
NSTEPS          NSTP2 = 1
ALGORITHM       IALG2 = 5
MAXTERVAL       MAXT2 = 0.01
MINTERVAL       MINT2 = 0.01

"----- Dynamic pressure (N/m**2) "

QBAR = 0.5 * RHO * VTW * VTW

"----- Angle of attack (deg) and sine of angle of attack "

ALFA   = ACOS(UW/VTW)
EPS    = SIN(ALFA)
EPSSQ  = EPS*EPS
VWoVTW = VW/VTW
WWoVTW = WW/VTW

"----- Aerodynamic force (per unit of mass) and gravity (m/sec**2) "

QAM     =  QBAR * AoMASS
PL2V    =  P * L2 / VTW

FbxDRG  = -QAM*CX
FbxG    =  G*SINTHE
Fbx     =  FbxDRG + FbxG

FbyNF   = -QAM*CNA*VWoVTW
FbyMAG  =  QAM*PL2V*CYPA*WWoVTW
Fby     =  FbyNF + FbyMAG

FbzNF   = -QAM*CNA*WWoVTW
FbzMAG  = -QAM*PL2V*CYPA*VWoVTW
FbzG    = -G*COSTHE
Fbz     =  FbzNF + FbzMAG + FbzG

"----- Derivative in body axes of projectile linear velocity relative "
"      to the Earth (m/sec**2)

UDOT = Fbx - THEDOT*W + PSIDOT*COSTHE*V
VDOT = Fby - PSIDOT * ( COSTHE*U + SINTHE*W )
WDOT = Fbz + PSIDOT*SINTHE*V + THEDOT*U

"----- Projectile linear velocities relative to the Earth along "
"      the body x,y,z axes (m/sec)

U    = INTEG ( UDOT,UIC )
V    = INTEG ( VDOT,VIC )
W    = INTEG ( WDOT,WIC )

VT   = SQRT ( U*U + V*V + W*W )
```

```
"----- Projectile linear velocities along the Earth axes (m/sec) "

       UPEE =  U*COSTHE*COSPSI - V*SINPSI + W*SINTHE*COSPSI
       VPEE =  U*COSTHE*SINPSI + V*COSPSI + W*SINTHE*SINPSI
       WPEE = -U*SINTHE                   + W*COSTHE
       PRJEE = SQRT( UPEE*UPEE + VPEE*VPEE + WPEE*WPEE )

"----- Projectile position in the Earth axes (m) "

       XE   = INTEG ( UPEE, XEIC  )
       YE   = INTEG ( VPEE, YEIC  )
       ALT  = INTEG ( WPEE, ALTIC )

"----- Ranges (m), line of sight unit vector, range rate (m/s) "

       HRANGE = SQRT( XE*XE + YE*YE )
       RNG    = SQRT( HRANGE*HRANGE + ALT*ALT )

       PROCEDURAL(AZIM,ELEV,XLOSE,YLOSE,ZLOSE,RRT,AZIMD,ELEVD = ...
                  XE,YE,ALT,RNG,UPEE,VPEE,WPEE)
         IF (RNG.EQ.0.0) GOTO LOS1
            XLOSE = XE  / RNG
            YLOSE = YE  / RNG
            ZLOSE = ALT / RNG
            AZIM  = ATAN2(YLOSE,XLOSE)
            ELEV  = ASIN(ZLOSE)
            GOTO LOS2
         LOS1..CONTINUE
            AZIM  = PSIIC
            ELEV  =-THEIC
            XLOSE = COS(ELEV)*COS(AZIM)
            YLOSE = COS(ELEV)*SIN(AZIM)
            ZLOSE = SIN(ELEV)
            AZIMD = 0.0
            ELEVD = 0.0
         LOS2..CONTINUE
         RRT = UPEE*XLOSE + VPEE*YLOSE + WPEE*ZLOSE
         IF (RNG.EQ.0.0) GO TO LOS3
            COSEL = COS(ELEV)
            IF (COSEL.GT.1.E-4) ELEVD = (WPEE-RRT*ZLOSE)/RNG/COSEL
            IF (COSEL.LE.1.E-4) ELEVD = 0.0
            AZIMD = (VPEE-RRT*YLOSE+ELEVD*ALT*SIN(AZIM))/XE
         LOS3..CONTINUE
       END $ " of PROCEDURAL "

"----- Aspect angle (rad) "

       COSASP = BOUND( -1.,1., XLOSE*COSTHE*COSPSI ...
                             + YLOSE*COSTHE*SINPSI ...
                             - ZLOSE*SINTHE )
```

```
        ASPECT = ACOS( COSASP )
"----- Aerodynamic moments per unit of inertia (N*m)/(Kg*m**2) "
                                                                          "
        " MSIGN =
        "  1   : Unstable projectile (needs spin to avoid tumbling)       "
        " -1   : Stable projectile

        CONSTANT MSIGN = 1.

        QALIX    =  QBAR * ALoIX
        QALIY    =  QBAR * ALoIY
        QALIY2   =  QALIY*L2

        Mbx      =  QALIX*PL2V*CLP

        MbySM    =  MSIGN*QALIY*CMA*WWoVTW
        MbyDM    =  QALIY2*CMQ*THEDOT/VTW
        MbyMAG   = -QALIY*PL2V*CNPA*VWoVTW
        Mby      =  MbySM + MbyDM + MbyMAG

        MbzSM    = -MSIGN*QALIY*CMA*VWoVTW
        MbzDM    =  QALIY2*CMQ*PSIDOT*COSTHE/VTW
        MbzMAG   = -QALIY*PL2V*CNPA*WWoVTW
        Mbz      =  MbzSM + MbzDM + MbzMAG
"----- Projectile angular accelerations (Euler angles) (rad/sec**2) "
        PHIDD  = Mbx + PSIDD*SINTHE + THEDOT*PSIDOT*COSTHE

        Mgyro1 = -PSIDOT*COSTHE*P*IXoIY
        THEDD  = Mby + Mgyro1 - PSIDOT*COSTHE*PSIDOT*SINTHE

        Mgyro2 = THEDOT*P*IXoIY
        PSIDD  = ( Mbz + THEDOT*2.*PSIDOT*SINTHE + Mgyro2 ) / COSTHE

        "THEDD  = Mby - PSIDOT*COSTHE* ( P*IXoIY + PSIDOT*SINTHE )"
        "PSIDD  = ( Mbz + THEDOT*(2.*PSIDOT*SINTHE + P*IXoIY) ) / COSTHE"
"----- Projectile angular velocities (Euler angles) (rad/sec) "

        THEDOT  = INTEG ( THEDD, THDTIC )
        PHIDOT  = INTEG ( PHIDD, PHDTIC )
        PSIDOT  = INTEG ( PSIDD, PSDTIC )
"----- Projectile attitude angles (Euler angles) (rad) "

        THE     = INTEG ( THEDOT, THEIC )
        PHI     = INTEG ( PHIDOT, PHIIC )
        PSI     = INTEG ( PSIDOT, PSIIC )

        PROCEDURAL ( = THE, PHI, PSI )
```

```
        IF ( THE .GT.  PI )  THE = THE - PI
        IF ( THE .LT. -PI )  THE = THE + PI

        IF ( PHI .GT.  PI )  PHI = PHI - PI
        IF ( PHI .LT. -PI )  PHI = PHI + PI

        IF ( PSI .GT.  PI )  PSI = PSI - PI
        IF ( PSI .LT. -PI )  PSI = PSI + PI

      END $ " of PROCEDURAL "

"----- Sine/cosine of Euler angles "

      SINTHE = SIN ( THE )
      COSTHE = COS ( THE )
      SINPSI = SIN ( PSI )
      COSPSI = COS ( PSI )

"----- Projectile spin rate about the longitudal axis (rad/sec) "

      P    = PHIDOT - PSIDOT*SINTHE
      P2   = P * P

"----- Wind velocity relative to the Earth in body axes (m/sec) "

      UAEB =  VWEEX * COSTHE*COSPSI + VWEEY * COSTHE*SINPSI
      VAEB = -VWEEX * SINPSI        + VWEEY * COSPSI
      WAEB =  VWEEX * SINTHE*COSPSI + VWEEY * SINTHE*SINPSI

"----- Projectile velocity relative to the atmosphere in body axes "
"      (m/sec)

      UW   = U - UAEB
      VW   = V - VAEB
      WW   = W - WAEB

"----- Total projectile velocity relative to the atmosphere (m/s) "

      VTW  = SQRT ( UW*UW + VW*VW + WW*WW )

"----- Projectile hitting ground "

      PROCEDURAL

      LOGICAL ALTCND $ CONSTANT ALTSTP = 0.0
      ALTCND = (T.GE.1.) .AND. (ALT.LT.ALTSTP)

      LOGICAL COND4
      CONSTANT VZLOW = 10.0

      COND4 = (WPEE.LE.VZLOW) .AND. (RUNFLG.EQ.4)
```

```
        TERMT( ALTCND .OR. COND4 )

        END $ "OF PROCEDURAL"

NOFF-W-IIF, "L ignored
   on output page 54; on input line 1041 of page 27 of file "ANALYSIS:[ARMAL
  END $ " of DERIVATIVE FAST "

  "----- Layer index "

        ILAYER = INT( ALT/LAYER ) + 1
        FSTLAY = INT( OLDALT/LAYER ) + 1
        OLDALT = ALT
        MAXLAY = AMAX0( MAXLAY , ILAYER )

  "----- Descent "

        LOGICAL DESCNT , CHANGE , DSCNT0

        CHANGE = (ILAYER.NE.FSTLAY) .AND. ((T-TCHNGE).GE.TCHNG0)
        IF( CHANGE ) TCHNGE = T

        DSCNT0 = (FSTLAY.GT.ILAYER) .OR. DSCNT0
        DESCNT = (RUNFLG.EQ.2) .AND. DSCNT0
        IF( CHANGE ) JLAYER = ILAYER
        ICOST  = LSW( DSCNT0 , 2*MAXLAY-JLAYER , JLAYER )

  "----- Simulation termination conditions "

        LOGICAL   ENDTIM, ENDLAY, ENDFLG, ENDCLO

        CONSTANT  TSTP   = 200.0    , WSTOP  = 0.0
        CONSTANT  UDOT99 = 1.E20    , VDOT99 = 1.E20    , WDOT99 = 1.E20

        "- Max sim time reached "

        ENDTIM = (T.GT.TSTP)

        "- End of altitude layer reached "

        ENDLAY = (ILAYER.GE.(STLAY+NLAYER)) .AND. (RUNFLG.EQ.2)

        "- End of closed loop estimation "

        ENDCLO = (RUNFLG.EQ.4).AND.(COUNT.GE.NAPEX-1.OR.COUNT.GE.NMEAS-1)

        ENDFLG = ENDTIM .OR. DESCNT .OR. ENDLAY .OR. OVFLOW .OR. ENDCLO

        TERMT( ENDFLG )

  "*************************************************************"
```

```
"------------------ SAVE DATA FOR PLOTTING USING PLOT10I"

      INTEGER          DATLEN , COUNT , LASTC
      CONSTANT         DATLEN = 1600  , DUMMY = 0.

      AZIMdg =  AZIM  * DTORAD
      ELVdeg =  ELEV  * DTORAD
      PSIdeg =  PSI   * DTORAD
      PHIdeg =  PHI   * DTORAD
      ALFdeg =  ALFA  * DTORAD
      SPINdg =  P     * DTORAD
      FREQ1  =  OMEGA1 / TWOPI
      FREQ2  =  OMEGA2 / TWOPI
      ALFMAX =  AMAX1( ALFMAX , ABS(ALFdeg) )
      THEdeg =  THE   * DTORAD
      ASPdeg =  ASPECT * DTORAD

"---- Smooth wind computation "

CONSTANT   VWXA1 = 0, VWXA0 = 0, VWXH1 = 5000, VWXH0 = 1000
CONSTANT   VWYA1 = 0, VWYA0 = 0, VWYH1 = 5000, VWYH0 = 1000

      DAX = VWXA1 - VWXA0
      DHX = (ALT - VWXH0)/(VWXH1 - VWXH0)

      IF (ALT.LT.VWXH0) VWXp = VWXA0
      IF (ALT.GT.VWXH1) VWXp = VWXA1
      IF (ALT.GE.VWXH0.AND.ALT.LE.VWXH1) ...
      VWXp = VWXA0 + 3*DAX*DHX*DHX - 2*DAX*DHX*DHX*DHX

      DAY = VWYA1 - VWYA0
      DHY = (ALT - VWYH0)/(VWYH1 - VWYH0)

      IF (ALT.LT.VWYH0) VWYp = VWYA0
      IF (ALT.GT.VWYH1) VWYp = VWYA1
      IF (ALT.GE.VWYH0.AND.ALT.LE.VWYH1) ...
      VWYp = VWYA0 + 3*DAY*DHY*DHY - 2*DAY*DHY*DHY*DHY

      COUNT = COUNT + 1

      IF (WPEE.LE.VZLOW .AND. RUNFLG.EQ.1 .AND. NAPEX.EQ.5555) ...
      NAPEX = COUNT-5
"-------------------------------------------------------------------"

      IF (RUNFLG.NE.1) GOTO NOSAVE

         TIMNOM(COUNT)  = T

         XNOM(COUNT)    = XE
         YNOM(COUNT)    = YE
```

```
ZNOM(COUNT)    = ALT

VXNOM(COUNT)   = UPEE
VYNOM(COUNT)   = VPEE
VZNOM(COUNT)   = WPEE

RHONOM(COUNT)  = RHO
VWXNOM(COUNT)  = VWEEX
VWYNOM(COUNT) = VWEEY

RNGNOM(COUNT)  = RNG
RRTNOM(COUNT)  = RRT
AZMNOM(COUNT)  = AZIM
ELVNOM(COUNT)  = ELEV
AZDNOM(COUNT)  = AZIMD
ELDNOM(COUNT)  = ELEVD

CALL RADARMEAS(RADFLG, ASPECT, HITMSS, RCSDB,   ...
               STNDB,  KSIGMA, ...
               RNG,    RRT,    ELEV,   AZIM,    ...
               RGRDAR, RRRDAR, ELRDAR, AZRDAR,  ...
               RGNOIS, RRNOIS, ELNOIS, AZNOIS)

LOGICAL NOHM $ CONSTANT NOHM = .FALSE.
IF (NOHM) HITMSS = 1.

CONSTANT ADSIG0 = 0.,     ADSIG1 = 0.    $ "?<SIG<?"
CONSTANT EDSIG0 = 0.,     EDSIG1 = 0.    $ "?<SIG<?"
ADNOIS  = (1. + ADSIG1*RNG) * GAUSS(0.0,ADSIG0)
EDNOIS  = (1. + EDSIG1*RNG) * GAUSS(0.0,EDSIG0)

IF (COUNT.NE.1) GO TO RADAR
   HITMSS = 1
   RGRDAR = RNG
   RRRDAR = RRT
   ELRDAR = ELEV
   AZRDAR = AZIM
   RGNOIS = 0.0
   RRNOIS = 0.0
   ELNOIS = 0.0
   AZNOIS = 0.0
RADAR..CONTINUE

HMFLAG(COUNT) = HITMSS     $ " 1: HIT, 0.001: MISS"

IF (HITMSS.EQ.1.) GO TO HIT1
   RGMEAS(COUNT) = RNG
   RRMEAS(COUNT) = RRT
   AZMEAS(COUNT) = AZIM
   ELMEAS(COUNT) = ELEV
   GO TO HIT2
HIT1..CONTINUE
```

```
        RGMEAS(COUNT) = RGRDAR
        RRMEAS(COUNT) = RRRDAR
        AZMEAS(COUNT) = AZRDAR
        ELMEAS(COUNT) = ELRDAR
      HIT2..CONTINUE

      IF (COUNT.GT.1) INTGRR = INTGRR + 0.5*CINT* ...
                               (RRMEAS(COUNT)+RRMEAS(COUNT-1))

      VWXPN (COUNT) = VWXP
      VWYPN (COUNT) = VWYP

    NOSAVE..CONTINUE

"----- Cost function computation "

    IF (CHANGE) KOUNT = 0

      KOUNT    = KOUNT + 1

      XNOM0    = XNOM(COUNT)
      YNOM0    = YNOM(COUNT)
      ZNOM0    = ZNOM(COUNT)

      VXNOM0   = VXNOM(COUNT)
      VYNOM0   = VYNOM(COUNT)
      VZNOM0   = VZNOM(COUNT)

      DX       =  XE  - XNOM0
      DY       =  YE  - YNOM0
      DZ       = ALT  - ZNOM0

      DVX      = UPEE - VXNOM0
      DVY      = VPEE - VYNOM0
      DVZ      = WPEE - VZNOM0

      RGMS     = RGMEAS(COUNT)
      RRMS     = RRMEAS(COUNT)
      AZMS     = AZMEAS(COUNT)
      ELMS     = ELMEAS(COUNT)

      INTEGER NANGLE $ CONSTANT NANGLE = 5
      IF (COUNT.GT.NANGLE) ...
      ADMS = (AZMS-AZMEAS(COUNT-NANGLE))/CINT/NANGLE
      IF (COUNT.GT.NANGLE) ...
      EDMS = (ELMS-ELMEAS(COUNT-NANGLE))/CINT/NANGLE

      SINAZ    = SIN(AZMS)
      COSAZ    = COS(AZMS)
      SINEL    = SIN(ELMS)
      COSEL    = COS(ELMS)
```

```
XMEAS     = RGMS * COSEL * COSAZ
YMEAS     = RGMS * COSEL * SINAZ
ZMEAS     = RGMS * SINEL

VXMEAS    = RRMS*COSEL*COSAZ - RGMS*EDMS*SINEL*COSAZ ...
                             - RGMS*ADMS*COSEL*SINAZ
VYMEAS    = RRMS*COSEL*SINAZ - RGMS*EDMS*SINEL*SINAZ ...
                             + RGMS*ADMS*COSEL*COSAZ
VZMEAS    = RRMS*SINEL + RGMS*EDMS*COSEL

XERR      =  XE - XMEAS
YERR      =  YE - YMEAS
ZERR      = ALT - ZMEAS

VXERR     = UPEE - VXMEAS
VYERR     = VPEE - VYMEAS
VZERR     = WPEE - VZMEAS

RGERR     = RNG - RGRDAR
RRERR     = RRT - RRRDAR

IF (RUNFLG.EQ.1) GOTO NOCOST

XCOST2          = XERR*XERR
YCOST2          = YERR*YERR
ZCOST2          = ZERR*ZERR

UCOST2          = DVX*DVX
VCOST2          = DVY*DVY
WCOST2          = DVZ*DVZ

LCOSTX          = XCOST2 + LVX*UCOST2
LCOSTY          = YCOST2 + LVY*VCOST2
LCOSTZ          = ZCOST2 + LVZ*WCOST2

COSTVX(ICOST) = ( (KOUNT-1)*COSTVX(ICOST) + LCOSTX ) / KOUNT
COSTVY(ICOST) = ( (KOUNT-1)*COSTVY(ICOST) + LCOSTY ) / KOUNT
COSTVZ(ICOST) = ( (KOUNT-1)*COSTVZ(ICOST) + LCOSTZ ) / KOUNT

IF (OVFLOW) COSTVX(ICOST) = 998001.
IF (OVFLOW) COSTVY(ICOST) = 998001.
IF (OVFLOW) COSTVZ(ICOST) = 998001.

COSTX           = SQRT(COSTVX(ICOST))
COSTY           = SQRT(COSTVY(ICOST))
COSTZ           = SQRT(COSTVZ(ICOST))

NCOST(ICOST)    = KOUNT

"-------- Feedback loops for control/identification of METs parameters "
```

```
LOGICAL   CLMET
CONSTANT  CLMET = .FALSE.

IF (.NOT.CLMET) GOTO NOCOST

   ARRAY ALTC(1600), RHOC(1600), VWXC(1600), VWYC(1600)
   CONSTANT ALTC = 1600*0., RHOC = 1600*0.
   CONSTANT VWXC = 1600*0., VWYC = 1600*0.
   ALTC(COUNT) = ALT
   RHOC(COUNT) = DRHOFB
   VWXC(COUNT) = DVWXFB
   VWYC(COUNT) = DVWYFB

NOCOST..CONTINUE
---------------------------------------------------------------------

IF( ALT .LT. 0.0 ) GOTO NOSAV1

RHOC0 = RHOCOR(ALT)
VWXC0 = VWXCOR(ALT)
VWYC0 = VWYCOR(ALT)
ZHOLE = RSW( HITMSS.EQ.1. , ZMEAS , 0.0 )

CALL SAVEDATAS ( DATLEN, COUNT , 1       ,                      ...
                 ALT   , U     , V       , W     , ELVdeg,      ...
                 PSIdeg, PHIdeg, XE      , YE    , T     ,      ...
                 ALFdeg, QBAR  , VTW     , XMEAS , YMEAS ,      ...
                 ZMEAS , VWXC0 , VWYC0   , COSTX , UW           )

CALL SAVEDATAS ( DATLEN, COUNT , 21      ,                      ...
                 VW    , WW    , SPINdg, RHO     , THEdeg,      ...
                 TEMPF , SQRT(ZCOST2)    , SQRT(WCOST2)  ,      ...
                 COSTZ , ELNOIS*DTORAD, ...
                 VT    , UAEB  , VAEB    , WAEB  , UPEE  ,      ...
                 VPEE  , WPEE  , Fbx     , Fby   , Fbz          )

CALL SAVEDATAS ( DATLEN, COUNT , 41      ,                      ...
             VXMEAS , VYMEAS , VZMEAS , MbySM , ZHOLE,          ...
             DRHOFB, VWEEX , VWXNOM(COUNT) , DVWXFB,            ...
             XNOM(COUNT),  YNOM(COUNT),  ZNOM(COUNT),           ...
             VXNOM(COUNT), VYNOM(COUNT), VZNOM(COUNT),          ...
             RHONOM(COUNT), CX , ELMEAS(COUNT)*DTORAD ,         ...
             MACH   , INTGRR )

CALL SAVEDATAS ( DATLEN, COUNT , 61      ,                      ...
           SG     , RGMEAS(COUNT), RRMEAS(COUNT), ...
           AZMEAS(COUNT)*DTORAD, RGNOIS, ...
           RRNOIS, AZNOIS*DTORAD, XERR  , YERR  , ZERR  ,       ...
           RCSDB, STNDB, THEDD , PHIDD , PSIDD , ...
           RNG    , VWXp  , RRT   , VWYp  , AZIMdg )
```

```
          CALL SAVEDATAS ( DATLEN, COUNT , 81       ,              ...
                VWEEY , VWYNOM(COUNT) , DX      , DY     , DZ     , ...
                DVX     , DVY     , DVZ     , TIMNOM(COUNT) , ...
                SQRT(YCOST2)    , SQRT(VCOST2)     , DVWYFB , ...
                RHOC0 , HITMSS , VXERR , VYERR   , ...
                VZERR , VWXPN(COUNT) , VWYPN(COUNT) , ASPdeg )
          NOSAV1..CONTINUE

NOFF-W-IIF, 'L ignored
     on output page 60; on input line 1358 of page 27 of file "ANALYSIS:[ARMAL
   END S " of DYNAMIC "

    "*******************************************************************"
                                TERMINAL
    "*******************************************************************"

        IF (.NOT.OVFLOW) GOTO NOOVF
           WRITE(20,123) T
           PRINT 123, T
           123..FORMAT(//,1X,35H***********************************, ...
                        /,1X,35H   WARNING ! Overflow prediction   , ...
                        /,1X,35H***********************************, ...
                        /,1X,10H----> T = , F10.3)
        NOOVF..CONTINUE

        IF (RUNFLG.NE.1) GOTO LEND1

           COUNT = COUNT + 1
           LASTC = COUNT

           TIMNOM(COUNT) = T

           XNOM(COUNT)    = XE
           YNOM(COUNT)    = YE
           ZNOM(COUNT)    = ALT

           VXNOM(COUNT)   = UPEE
           VYNOM(COUNT)   = VPEE
           VZNOM(COUNT)   = WPEE

           RHONOM(COUNT) = RHO
           VWXNOM(COUNT) = VWEEX
     VWYNOM(COUNT) = VWEEY

           RNGNOM(COUNT) = RNG   + RGNOIS
           RRTNOM(COUNT) = RRT   + RRNOIS
           AZMNOM(COUNT) = AZIM  + AZNOIS
           ELVNOM(COUNT) = ELEV  + ELNOIS
           AZDNOM(COUNT) = AZIMD + ADNOIS
           ELDNOM(COUNT) = ELEVD + EDNOIS
```

```
      VWXPN (COUNT) = VWXP
      VWYPN (COUNT) = VWYP

      HMFLAG(COUNT) = HITMSS

      RGMEAS(COUNT) = RSW( HITMSS.EQ.1. , RGRDAR , RNG )
      RRMEAS(COUNT) = RSW( HITMSS.EQ.1. , RRRDAR , RRT )
      AZMEAS(COUNT) = RSW( HITMSS.EQ.1. , AZRDAR , AZIM )
      ELMEAS(COUNT) = RSW( HITMSS.EQ.1. , ELRDAR , ELEV )

      CALL SAVEINFO(1 , XE    , YE    , ALT    , 0.0    , 0.0    , ...
                        0.0   , 0.0   , 0.0    , 0.0    , 0.0    )

      CALL NAMEOFPLOT
      CALL PLOTROUTINE
      IF (.NOT.NOHM) CALL PROCESSMEAS

   LEND1..CONTINUE

   IF (RUNFLG.NE.3) GOTO LEND2

      XNOM0   = XNOM(LASTC)
      YNOM0   = YNOM(LASTC)
      ZNOM0   = ZNOM(LASTC)

      VXNOM0  = VXNOM(LASTC)
      VYNOM0  = VYNOM(LASTC)
      VZNOM0  = VZNOM(LASTC)

      DX      =  XE - XNOM0
      DY      =  YE - YNOM0
      DZ      = ALT - ZNOM0

      DVX     = UPEE - VXNOM0
      DVY     = VPEE - VYNOM0
      DVZ     = WPEE - VZNOM0

 DIMPAC = SQRT( DX*DX + DY*DY )
       CALL SAVEINFO(11, XE    , YE    , ALT    , DIMPAC, LVX, ...
                         LVY   , LVZ   , DX     , DY    , 0.0  )

       CALL NAMEOFPLOT
       CALL PLOTROUTINE

    LEND2..CONTINUE

    IF (RUNFLG.NE.4) GO TO LEND3
       CALL SAVEINFO(21, KZER, KVZER, TAUVZ, KXER, KVXER, ...
                         TAUVX, KYER, KVYER, TAUVY, 0.0)
```

```
          CALL NAMEOFPLOT
          CALL PLOTROUTINE
       LEND3..CONTINUE

   END S " of TERMINAL "

INOFF-W-IIF, 'L ignored
     on output page 62; on input line 1459 of page 27 of file "ANALYSIS:[ARMAL
   END S " of PROGRAM "
        SUBROUTINE NAMEOFPLOT

        INCLUDE 'COMPLOT'

        NAME( 1) = 'ALT     '
        NAME( 2) = 'U       '
        NAME( 3) = 'V       '
        NAME( 4) = 'W       '
        NAME( 5) = 'ELEV    '
        NAME( 6) = 'PSI     '
        NAME( 7) = 'PHI     '
        NAME( 8) = 'XE      '
        NAME( 9) = 'YE      '
        NAME(10) = 'TIME    '
        NAME(11) = 'ALFA    '
        NAME(12) = 'QBAR    '
        NAME(13) = 'VTW     '
        NAME(14) = 'XMEAS   '
        NAME(15) = 'YMEAS   '
        NAME(16) = 'ZMEAS   '
        NAME(17) = 'VWXCOR  '
        NAME(18) = 'VWYCOR  '
        NAME(19) = 'COSTVX  '
        NAME(20) = 'UW      '

        NAME(21) = 'VW      '
        NAME(22) = 'WW      '
        NAME(23) = 'SPINRATE'
        NAME(24) = 'RHO     '
        NAME(25) = 'THETA   '
        NAME(26) = 'TEMPK   '
        NAME(27) = 'ZCOST   '
        NAME(28) = 'WCOST   '
        NAME(29) = 'COSTVZ  '
        NAME(30) = 'ELNOIS  '
        NAME(31) = 'VT      '
        NAME(32) = 'UAEB    '
        NAME(33) = 'VAEB    '
        NAME(34) = 'WAEB    '
        NAME(35) = 'UPEE    '
        NAME(36) = 'VPEE    '
        NAME(37) = 'WPEE    '
        NAME(38) = 'Fbx     '
        NAME(39) = 'Fby     '
        NAME(40) = 'Fbz     '
```

```
NAME(41) = 'VXMEAS'
NAME(42) = 'VYMEAS'
NAME(43) = 'VZMEAS'
NAME(44) = 'MbySM  '
NAME(45) = 'ZDETECTED'
NAME(46) = 'DRHOFB'
NAME(47) = 'VWEEX  '
NAME(48) = 'VWXNOM'
NAME(49) = 'DVWXFB'
NAME(50) = 'XNOM   '
NAME(51) = 'YNOM   '
NAME(52) = 'ZNOM   '
NAME(53) = 'VXNOM  '
NAME(54) = 'VYNOM  '
NAME(55) = 'VZNOM  '
NAME(56) = 'RHONOM'
NAME(57) = 'CX     '
NAME(58) = 'ELMEAS'
NAME(59) = 'MACH   '
NAME(60) = 'INTGRR'

NAME(61) = 'SG     '
NAME(62) = 'RGMEAS'
NAME(63) = 'RRMEAS'
NAME(64) = 'AZMEAS'
NAME(65) = 'RGNOIS'
NAME(66) = 'RRNOIS'
NAME(67) = 'AZNOIS'
NAME(68) = 'XERR   '
NAME(69) = 'YERR   '
NAME(70) = 'ZERR   '
NAME(71) = 'RCSDB  '
NAME(72) = 'STNDB  '
NAME(73) = 'THEDD  '
NAME(74) = 'PHIDD  '
NAME(75) = 'PSIDD  '
NAME(76) = 'RANG   '
NAME(77) = 'VWXP   '
NAME(78) = 'RNGRAT'
NAME(79) = 'VWYP   '
NAME(80) = 'AZIM   '

NAME(81) = 'VWEEY  '
NAME(82) = 'VWYNOM'
NAME(83) = 'DX     '
NAME(84) = 'DY     '
NAME(85) = 'DZ     '
NAME(86) = 'DVX    '
NAME(87) = 'DVY    '
NAME(88) = 'DVZ    '
NAME(89) = 'TIMNOM'
```

```
      NAME(90) =  'YCOST  '
      NAME(91) =  'VCOST  '
      NAME(92) =  'DVWYFB'
      NAME(93) =  'RHOCOR'
      NAME(94) =  'HITMSS'
      NAME(95) =  'VXERR'
      NAME(96) =  'VYERR'
      NAME(97) =  'VZERR'
      NAME(98) =  'VWXPN'
      NAME(99) =  'VWYPN'
      NAME(100)=  'ASPECT'

      NAME(101)=  'RGMEAS2'
      NAME(102)=  'RRMEAS2'
      NAME(103)=  'ELMEAS2'
      NAME(104)=  'AZMEAS2'

      INFO( 1) =  'XIMPC0'
      INFO( 2) =  'YIMPC0'
      INFO( 3) =  'ZIMPC0'
      INFO( 4) =  ' '
      INFO( 5) =  ' '
      INFO( 6) =  ' '
      INFO( 7) =  ' '
      INFO( 8) =  ' '
      INFO( 9) =  ' '
      INFO(10) =  ' '
      INFO(11) =  'XIMPC1'
      INFO(12) =  'YIMPC1'
      INFO(13) =  'ZIMPC1'
      INFO(14) =  'LIMPAC'
      INFO(15) =  'LVX'
      INFO(16) =  'LVY'
      INFO(17) =  'LVZ'
      INFO(18) =  'DXIMPAC'
      INFO(19) =  'DYIMPAC'
      INFO(20) =  ' '
      INFO(21) =  'KZER   '
      INFO(22) =  'KVZER  '
      INFO(23) =  'TAUVZ  '
      INFO(24) =  'KXER   '
      INFO(25) =  'KVXER  '
      INFO(26) =  'TAUVX  '
      INFO(27) =  'KYER   '
      INFO(28) =  'KVYER  '
      INFO(29) =  'TAUVY  '
      INFO(30) =  ' '

      RETURN
      END
C*********************************************************************
```

```
      SUBROUTINE SET_ACSL_PARAM (
     1     RUNFLGi , RADFLGi , RNSEEDi , NLAYERi , RHOTABi
     1,    VWXTABi , VWYTABi , LVXi    , LVYi    , LVZi
     1,    VWXH0i  , VWXA0i  , VWXH1i  , VWXA1i  , VWYH0i
     1,    VWYA0i  , VWYH1i  , VWYA1i  , CLMETi  , TSTPi
     1,    KXERi   , KVXERi  , KAXERi  , KYERi   , KVYERi
     1,    KAYERi  , KZERi   , KVZERi  , KAZERi  , KRGERi
     1,    KRRERi  )
C******************************************************************
C
C     PASS ARGUMENTS TO ZZCOM
C
C******************************************************************
$     ZZCOM
      INTEGER RUNFLGi, RADFLGi, RNSEEDi, NLAYERi
      REAL    RHOTABi(40), VWXTABi(40), VWYTABi(40)
      REAL    LVXi, LVYi, LVZi
      REAL    TSTPi
      LOGICAL CLMETi
      REAL    KXERi, KVXERi, KAXERi
      REAL    KYERi, KVYERi, KAYERi
      REAL    KZERi, KVZERi, KAZERi
      REAL    KRGERi, KRRERi

      RUNFLG  = RUNFLGi
      RADFLG  = RADFLGi
      RNSEED  = RNSEEDi
      NLAYER  = NLAYERi

      CLMET   = CLMETi
      IF (TSTPi.GE.0.) TSTP = TSTPi
      KXER    = KXERi
      KVXER   = KVXERi
      KAXER   = KAXERi
      KYER    = KYERi
      KVYER   = KVYERi
      KAYER   = KAYERi
      KZER    = KZERi
      KVZER   = KVZERi
      KAZER   = KAZERi
      KRGER   = KRGERi
      KRRER   = KRRERi

      DO I = 1, 20
         RHOTAB(i) = RHOTABi(I)
         VWXTAB(i) = VWXTABi(I)
         VWYTAB(i) = VWYTABi(I)
```

```
      END DO

      LVX = LVXi
      LVY = LVYi
      LVZ = LVZi

      VWXH0  = VWXH0i
      VWXA0  = VWXA0i
      VWXH1  = VWXH1i
      VWXA1  = VWXA1i

      VWYH0  = VWYH0i
      VWYA0  = VWYA0i
      VWYH1  = VWYH1i
      VWYA1  = VWYA1i

      RETURN
      END

      SUBROUTINE GET_ACSL_PARAM (
     1       MLAYERo  , COSTVXo  , COSTVYo  , COSTVZo  , NCOSTo
     1,      KXERo    , KVXERo   , KAXERo   , KYERo    , KVYERo
     1,      KAYERo   , KZERo    , KVZERo   , KAZERo   , KRGERo
     1,      KRRERo   , RHOTABo  , VWXTABo  , VWYTABo  )
C*********************************************************************
C
C RETRIEVE VARIABLES FROM ZZCOM
C
C*********************************************************************

$ ZZCOM

      INTEGER MLAYERo, NCOSTo(40)
      REAL COSTVXo(40), COSTVYo(40), COSTVZo(40)
      REAL    KXERo, KVXERo, KAXERo
      REAL    KYERo, KVYERo, KAYERo
      REAL    KZERo, KVZERo, KAZERo
      REAL    KRGERo, KRRERo
      REAL    RHOTABo(40), VWXTABo(40), VWYTABo(40)

      IF (RUNFLG.EQ.1) MLAYERo = MAXLAY

      DO I = 1, 40
              COSTVXo(I) = COSTVX(I)
              COSTVYo(I) = COSTVY(I)
              COSTVZo(I) = COSTVZ(I)
              NCOSTo  (I) = NCOST (I)
         RHOTABo(I) = RHOTAB(I)
         VWXTABo(I) = VWXTAB(I)
         VWYTABo(I) = VWYTAB(I)
```

```
      END DO

      KXERo    = KXER
      KVXERo   = KVXER
      KAXERo   = KAXER
      KYERo    = KYER
      KVYERo   = KVYER
      KAYERo   = KAYER
      KZERo    = KZER
      KVZERo   = KVZER
      KAZERo   = KAZER
      KRGERo   = KRGER
      KRRERo   = KRRER

      RETURN
      END

C***********************************************************************
C
      SUBROUTINE SAVENOMINAL( FILE )
C
C***********************************************************************

$ ZZCOM

      CHARACTER*10 FILE

      REAL XNOMsav(1600),     YNOMsav(1600),     ZNOMsav(1600)
      REAL VXNOMsav(1600),    VYNOMsav(1600),    VZNOMsav(1600)
      REAL RHONOMsav(1600),   VWXNOMsav(1600),   VWYNOMsav(1600)
      REAL RNGNOMsav(1600),   RRTNOMsav(1600),   TIMNOMsav(1600)
      REAL AZMNOMsav(1600),   ELVNOMsav(1600)
      REAL AZDNOMsav(1600),   ELDNOMsav(1600)
           REAL VWXPNsav(1600),   VWYPNsav(1600)
      REAL RGMEASsav(1600),   RRMEASsav(1600)
      REAL AZMEASsav(1600),   ELMEASsav(1600)
      REAL HMFLAGsav(1600)

      INTEGER I, COUNTsav
      INTEGER NAPEXsav

C------ Save current ZZCOM arrays

      PRINT *, 'Save nominal values in x.BIN file'

      NAPEXsav = NAPEX
      COUNTsav = COUNT

C PRINT *, ' COUNTsav ', COUNTsav
```

```
DO I = 1 , COUNTsav
   XNOMsav(I)    = XNOM(I)
   YNOMsav(I)    = YNOM(I)
   ZNOMsav(I)    = ZNOM(I)
   VXNOMsav(I)   = VXNOM(I)
   VYNOMsav(I)   = VYNOM(I)
   VZNOMsav(I)   = VZNOM(I)
   RHONOMsav(I)  = RHONOM(I)
   VWXNOMsav(I)  = VWXNOM(I)
   VWYNOMsav(I)  = VWYNOM(I)
   RNGNOMsav(I)  = RNGNOM(I)
   RRTNOMsav(I)  = RRTNOM(I)
   TIMNOMsav(I)  = TIMNOM(I)
   AZMNOMsav(I)  = AZMNOM(I)
   ELVNOMsav(I)  = ELVNOM(I)
   AZDNOMsav(I)  = AZDNOM(I)
   ELDNOMsav(I)  = ELDNOM(I)
          VWXPNsav(I)   = VWXPN(I)
          VWYPNsav(I)   = VWYPN(I)
   RGMEASsav(I)  = RGMEAS(I)
   RRMEASsav(I)  = RRMEAS(I)
   AZMEASsav(I)  = AZMEAS(I)
   ELMEASsav(I)  = ELMEAS(I)
   HMFLAGsav(I)  = HMFLAG(I)
END DO

C------ Restore ZZCOM from FILE

  CALL ZZSVRS2( 0, FILE)

C------ Transfer saved arrays into new ZZCOM

  LASTC = COUNTsav
  NAPEX = NAPEXsav

  DO I = 1 , COUNTsav
     XNOM(I)    = XNOMsav(I)
     YNOM(I)    = YNOMsav(I)
     ZNOM(I)    = ZNOMsav(I)
     VXNOM(I)   = VXNOMsav(I)
     VYNOM(I)   = VYNOMsav(I)
     VZNOM(I)   = VZNOMsav(I)
     RHONOM(I)  = RHONOMsav(I)
     VWXNOM(I)  = VWXNOMsav(I)
     VWYNOM(I)  = VWYNOMsav(I)
     RNGNOM(I)  = RNGNOMsav(I)
     RRTNOM(I)  = RRTNOMsav(I)
     TIMNOM(I)  = TIMNOMsav(I)
     AZMNOM(I)  = AZMNOMsav(I)
     ELVNOM(I)  = ELVNOMsav(I)
     AZDNOM(I)  = AZDNOMsav(I)
```

```
      ELDNOM(I)  = ELDNOMsav(I)
            VWXPN(I)   = VWXPNsav(I)
            VWYPN(I)   = VWYPNsav(I)
      RGMEAS(I)  = RGMEASsav(I)
      RRMEAS(I)  = RRMEASsav(I)
      AZMEAS(I)  = AZMEASsav(I)
      ELMEAS(I)  = ELMEASsav(I)
      HMFLAG(I)  = HMFLAGsav(I)
   END DO
C------ Fill additional elements with last nominal values
   DO I = MIN(1600,COUNTsav+1) , MIN(1600,COUNTsav+10)
      XNOM(I)    = XNOMsav(COUNTsav)
      YNOM(I)    = YNOMsav(COUNTsav)
      ZNOM(I)    = ZNOMsav(COUNTsav)
      VXNOM(I)   = VXNOMsav(COUNTsav)
      VYNOM(I)   = VYNOMsav(COUNTsav)
      VZNOM(I)   = VZNOMsav(COUNTsav)
      RHONOM(I)  = RHONOMsav(COUNTsav)
      VWXNOM(I)  = VWXNOMsav(COUNTsav)
      VWYNOM(I)  = VWYNOMsav(COUNTsav)
      RNGNOM(I)  = RNGNOMsav(COUNTsav)
      RRTNOM(I)  = RRTNOMsav(COUNTsav)
      TIMNOM(I)  = TIMNOMsav(COUNTsav)
      AZMNOM(I)  = AZMNOMsav(COUNTsav)
      ELVNOM(I)  = ELVNOMsav(COUNTsav)
            VWXPN(I)   = VWXPNsav(COUNTsav)
            VWYPN(I)   = VWYPNsav(COUNTsav)
      RGMEAS(I)  = RGMEASsav(COUNTsav)
      RRMEAS(I)  = RRMEASsav(COUNTsav)
      AZMEAS(I)  = AZMEASsav(COUNTsav)
      ELMEAS(I)  = ELMEASsav(COUNTsav)
      HMFLAG(I)  = HMFLAGsav(COUNTsav)
   END DO
C------ Save modified ZZCOM back into FILE
   CALL ZZSVRS2( 1, FILE)
   RETURN
   END
C***********************************************************************

C***********************************************************************
C
   SUBROUTINE SAVECORRECTION( FILE , NBPMAX , ICORRECT )
C
C***********************************************************************

$ ZZCOM
```

```
      CHARACTER*10 FILE
      INTEGER NBPMAX, ICORRECT, NBPsav, NBREAKPOINTS, I, J
      REAL RHOCORsav(3200), VWXCORsav(3200), VWYCORsav(3200)
      REAL FLNEAR, ALTITUDE
      REAL SMOOTHED(1600), COEFF(3)
      REAL AVERAGED(1600), WEIGHTO(100)
      INTEGER NWEIGHT/50/
      DATA WEIGHTO / 25*1., 25*0.5, 50*0.25 /
      INTEGER WEIGHT_POWER/0/, IER_LSQ
      REAL RHO_WEIGHTS(1600)

C------ Transfer xxxTAB into xxxC (with xxx = RHO, VWX, VWY) so that the
C------ estimated parameter xxx is in xxxCOR which then can be smoothed

      IF (ICORRECT.EQ.0) THEN
         DO I = 1 , COUNT
            ALTITUDE = ALTC(I)
            RHOC(I) = RHOC(I) + FLNEAR(20,20,RHOTAB,ALTITUDE)
            VWXC(I) = VWXC(I) + FLNEAR(20,20,VWXTAB,ALTITUDE)
            VWYC(I) = VWYC(I) + FLNEAR(20,20,VWYTAB,ALTITUDE)
         END DO ! I
      END IF

C------ Sum-up correction values at the different breakpoints

      IF (ICORRECT.NE.0) THEN
         DO I = 1 , COUNT
            ALTITUDE = ALTC(I)
            RHOC(I) = RHOC(I) + FLNEAR(NBPMAX,NBP,RHOCOR,ALTITUDE)
            VWXC(I) = VWXC(I) + FLNEAR(NBPMAX,NBP,VWXCOR,ALTITUDE)
            VWYC(I) = VWYC(I) + FLNEAR(NBPMAX,NBP,VWYCOR,ALTITUDE)
         END DO ! I
      END IF

C------ Smooth-out RHOC with a quadratic polynomial

      IF (DBFLAG.EQ.1.) THEN
         PRINT *, ' TAR> Smooth out RHO ? (1:yes, 0:no) : '
         READ(5,*) I
      ELSE
         I = 1
      END IF

      IF (I.EQ.1) THEN

         I = MIN( COUNT , NMEAS )
         CALL LSQ_POLY2( COEFF, ALTC, RHOC, I)

         DO I = 1 , COUNT
            SMOOTHED(I) = COEFF(3) + ALTC(I) * ( COEFF(2)
     +                          + ALTC(I) * COEFF(1) )
```

```
    END DO ! I

    CALL PLOTSMOOTHED( SMOOTHED, ALTC, RHOC, COUNT)

    IF (DBFLAG.EQ.1.) THEN
       PRINT *, ' TAR> Keep smoothed RHO ? (1:yes, 0:no) : '
       READ(5,*) I
    ELSE
       I = 1
    END IF

    IF (I.EQ.1) THEN
       DO I = 1 , COUNT
          RHOC(I) = SMOOTHED(I)
       END DO ! I
    END IF

  END IF

C------ Smooth-out VWX by averaging

  IF (DBFLAG.EQ.1.) THEN
     PRINT *, ' TAR> Smooth out VWX ? (1:yes, 0:no) : '
     READ(5,*) I
  ELSE
     I = 1
  END IF

  IF (I.EQ.1) THEN
200           CONTINUE

     J = MIN( COUNT , NMEAS )
     CALL MOV_AVERAGE( AVERAGED, VWXC, J, WEIGHT0, NWEIGHT)

     DO I = NMEAS+1 , COUNT
        AVERAGED(I) = AVERAGED(NMEAS)
     END DO

     ! limit max wind variation to MXWDSL (m/sec)/m
     CALL LIMIT_WIND( AVERAGED, ALTC, COUNT, MXWDSL)

     CALL PLOTSMOOTHED( AVERAGED, ALTC, VWXC, COUNT)

     IF (DBFLAG.EQ.1.) THEN
        PRINT *, ' TAR> Keep smoothed VWX ? (1:yes, 0:no) : '
        READ(5,*) I
     ELSE
        I = 1
     END IF

     IF (I.EQ.1) THEN
```

```
          DO I = 1 , COUNT
             VWXC(I) = AVERAGED(I)
          END DO ! I
       ELSE
          PRINT *, ' TAR> Change weights ? (1:yes, 0:no) : '
                   READ(5,*) I
          IF (I.NE.1) GO TO 290
          PRINT *, ' TAR> Number of weights ? :', NWEIGHT
          READ(5,*) NWEIGHT
          IF (NWEIGHT.LE.0) GO TO 290
          PRINT *, ' TAR> Enter weights :'
          PRINT 250, (WEIGHT0(I),I=1,NWEIGHT)
250                FORMAT(7X, 10(1X,F5.2), 9(/,7X,10(1X,F5.2)) )
          READ(5,*) WEIGHT0
          GO TO 200
       END IF

  END IF

290       CONTINUE

C------ Smooth-out VWY by averaging

  IF (DBFLAG.EQ.1.) THEN
     PRINT *, ' TAR> Smooth out VWY ? (1:yes, 0:no) : '
     READ(5,*) I
  ELSE
     I = 1
  END IF

  IF (I.EQ.1) THEN

300          CONTINUE

     J = MIN( COUNT , NMEAS )
     CALL MOV_AVERAGE( AVERAGED, VWYC, J, WEIGHT0, NWEIGHT)

     DO I = NMEAS+1 , COUNT
        AVERAGED(I) = AVERAGED(NMEAS)
     END DO

     ! limit max wind variation to MXWDSL (m/sec)/m
     CALL LIMIT_WIND( AVERAGED, ALTC, COUNT, MXWDSL)

     CALL PLOTSMOOTHED( AVERAGED, ALTC, VWYC, COUNT)

     IF (DBFLAG.EQ.1.) THEN
        PRINT *, ' TAR> Keep smoothed VWY ? (1:yes, 0:no) : '
        READ(5,*) I
     ELSE
        I = 1
     END IF
```

```
      IF (I.EQ.1) THEN
         DO I = 1 , COUNT
            VWYC(I) = AVERAGED(I)
         END DO ! I
      ELSE
         PRINT *, ' TAR> Change weights ? (1:yes, 0:no) : '
              READ(5,*) I
         IF (I.NE.1) GO TO 390
         PRINT *, ' TAR> Number of weights ? :', NWEIGHT
         READ(5,*) NWEIGHT
         IF (NWEIGHT.LE.0) GO TO 390
         PRINT *, ' TAR> Enter weights :'
         PRINT 250, (WEIGHT0(I),I=1,NWEIGHT)
         READ(5,*) WEIGHT0
         GO TO 300
      END IF

   END IF

390      CONTINUE

C------ Load values into "sav" arrays

   NBPsav = COUNT

   DO I = 1 , NBPsav

      J = I+NBPMAX      ! index of independent value

      RHOCORsav(I) = RHOC(I)
      RHOCORsav(J) = ALTC(I)
      VWXCORsav(I) = VWXC(I)
      VWXCORsav(J) = ALTC(I)
      VWYCORsav(I) = VWYC(I)
      VWYCORsav(J) = ALTC(I)

   END DO ! I

C------ Add values into arrays (for extrapolation use) if enough room

   I = COUNT + 1

   IF (I.LE.NBPMAX) THEN

      NBPsav = I
      J = I+NBPMAX

      ALTITUDE = 2.*ALTC(COUNT)

      RHOCORsav(I) = RHOCORsav(COUNT)
      RHOCORsav(J) = ALTITUDE
```

```
      VWXCORsav(I) = VWXCORsav(COUNT)
      VWXCORsav(J) = ALTITUDE

      VWYCORsav(I) = VWYCORsav(COUNT)
      VWYCORsav(J) = ALTITUDE

    END IF

C------ Save correction tables into nominal ZZCOM file

    CALL ZZSVRS2( 0 , FILE )   ! restore

    NBP = NBPsav

    DO I = 1 , NBP

      J = I+NBPMAX     ! index of independent value

      RHOCOR(I) = RHOCORsav(I)
      RHOCOR(J) = RHOCORsav(J)
      VWXCOR(I) = VWXCORsav(I)
      VWXCOR(J) = VWXCORsav(J)
      VWYCOR(I) = VWYCORsav(I)
      VWYCOR(J) = VWYCORsav(J)

    END DO ! I

    IF (ICORRECT.EQ.0) THEN          ! erase xxxTAB since their values
      DO I = 1 , 20                  ! have been transfered to xxxC
        RHOTAB(I) = 0.0              ! at the beginning
        VWXTAB(I) = 0.0
        VWYTAB(I) = 0.0
      END DO ! I
    END IF

    CALL ZZSVRS2( 1 , FILE ) ! save

    RETURN
    END
C**********************************************************************


C**********************************************************************
C
    SUBROUTINE PROCESSMEAS
C
C This routine processes the radar measurements prior to their use
C to drive the closed loop estimation algorithm.
C The range, range rate, elevation angle and azimuth angle are considered
C as functions of time and approximated by polynomials of order P_ORDER
```

```
C in a least-square sense (approximation up to T=NWEIGH*CINT).
C The purpose is twofold:
C - to provide "pseudo-measurements" when HITMSS is zero,
C - to smooth out the noise in the measurements.
C
C***********************************************************************

$ ZZCOM

C IMPLICIT NONE
C REAL RGMEAS(1), RRMEAS(1), ELMEAS(1), AZMEAS(1), TIMNOM(1)
C REAL MEASW(1), HMFLAG(1), DTORAD
C INTEGER NWEIGH, COUNT, DATIEN

  INTEGER
     .   P_ORDER              ! polynomial order
     ., PI                    ! polynomial order + 1

  PARAMETER (P_ORDER=2, PI=P_ORDER+1)

  INTEGER
     .   N_DATA               ! number of data points for approximation
     ., PIb/3/                ! actual polynomial order + 1
     ., NSEGMENT/2/           ! number of time segments considered in NWEIGH*CI
     ., ISEGMENT  ! index
     ., INDEX1, INDEX2        ! indices
     ., I, J                  ! indices
     ., RNGOPTION/1/          ! option index
     ., NEXTRA                !

  REAL
     .   P_COEF(P1)           ! polynomial coefficients
     ., TWORK(1600)           ! work array for time
     ., RGWORK(1600)          ! work array for range
     ., RRWORK(1600)          ! work array for range range
     ., ELWORK(1600)          ! work array for elevation
     ., AZWORK(1600)          ! work array for azimuth
     ., WKARRAY1(1600)        ! work array

  INTEGER
     .   N_AV_WEIGHT/20/      ! number of weights for moving average
     ., NPOINTS               ! total number of points in sequence to smooth ou

  REAL
     .   AV_WEIGHTS(50)       ! weights for moving average
  DATA AV_WEIGHTS/10*1.,10*0.5,30*0./

C-----------------------------------------------------------------------
C------ Parameter initialization
```

```
C------------------------------------------------------------------------
      IF (NWEIGH.LE.1) RETURN
      PRINT *, 'Processing measurements ...'
      NWEIGH = MIN( NMEAS , NAPEX )

C------------------------------------------------------------------------
C------ Loop over the NSEGMENTs of time to fill out the measurement holes w
C------ polynomial approximations
C------------------------------------------------------------------------

100   CONTINUE

      IF (DBFLAG.EQ.1.) THEN
         PRINT *, 'Number of time segments (min=1) ? default ='
     .,         NSEGMENT
         READ(5,*) NSEGMENT
         NSEGMENT = MAX( NSEGMENT , 1 )
      END IF

      DO ISEGMENT = 1 , NSEGMENT

         INDEX1 = NWEIGH*(ISEGMENT-1)/NSEGMENT + 1
         INDEX2 = NWEIGH*ISEGMENT/NSEGMENT

C--------- Make sure there are enough data points

200      N_DATA = 0

         PRINT *, INDEX1, INDEX2, NWEIGH

         DO I = INDEX1 , INDEX2
            IF (HMFLAG(I).EQ.1.) N_DATA = N_DATA + 1
         END DO

         IF (N_DATA.LT.P1b) THEN
            PRINT *, 'Not enough data points.', N_DATA
            IF (ISEGMENT.EQ.1) THEN
               INDEX2 = INDEX2 + 1
               IF (INDEX2.GT.NWEIGH) THEN
                  NWEIGH = NWEIGH + 1
                  IF (NWEIGH.GE.COUNT) THEN
                     PRINT *, 'Not enough data points. Run will be'
     .,                 'terminated after this plot session.'
                     CALL PLOTROUTINE
                     STOP 'Radar performance to be increased !'
                  END IF
                  GO TO 100
               END IF
            ELSE
               INDEX1 = INDEX1 - 1
```

```
         END IF
         GO TO 200
      END IF

C---------- Process range measurements
      PRINT *, '    range'

      N_DATA = 0
      DO I = INDEX1 , INDEX2
         IF (HMFLAG(I).EQ.1.) THEN
            N_DATA                = N_DATA + 1
            WKARRAY1(N_DATA)      = RGMEAS(I)
            TWORK(N_DATA)         = TIMNOM(I)
         END IF
      END DO

      IF (N_DATA.LT.3) THEN
         PRINT *, 'Error. N_DATA = ', N_DATA
         STOP
      END IF

      CALL LSQ_POLY2( P_COEF, TWORK, WKARRAY1, N_DATA)

      DO I = INDEX1 , INDEX2+NEXTRA
         IF (HMFLAG(I).NE.1.) THEN
            RGWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               RGWORK(I) = RGWORK(I) * TIMNOM(I) + P_COEF(J)
            END DO
         ELSE
            RGWORK(I) = RGMEAS(I)
         END IF
      END DO

      IF (ISEGMENT.EQ.NSEGMENT) THEN
         DO I = NWEIGH+1 , NAPEX+NEXTRA
            RGWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               RGWORK(I) = RGWORK(I) * TIMNOM(I) + P_COEF(J)
            END DO
         END DO
      END IF

C---------- Process range rate measurements
      PRINT *, '    range rate'

      N_DATA = 0
      DO I = INDEX1 , INDEX2
         IF (HMFLAG(I).EQ.1.) THEN
            N_DATA                = N_DATA + 1
            WKARRAY1(N_DATA)      = RRMEAS(I)
         END IF
```

```
      END DO

      IF (N_DATA.LT.3) THEN
         PRINT *, 'Error. N_DATA = ', N_DATA
         STOP
      END IF

      CALL LSQ_POLY2( P_COEF, TWORK, WKARRAY1, N_DATA)

      DO I = INDEX1 , INDEX2+NEXTRA
         IF (HMFLAG(I).NE.1.) THEN
            RRWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               RRWORK(I) = RRWORK(I) * TIMNOM(I) + P_COEF(J)
            END DO
         ELSE
            RRWORK(I) = RRMEAS(I)
         END IF
      END DO

      IF (ISEGMENT.EQ.NSEGMENT) THEN
         DO I = NWEIGH+1 , NAPEX+NEXTRA
            RRWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               RRWORK(I) = RRWORK(I) * TIMNOM(I) + P_COEF(J)
            END DO
         END DO
      END IF

C--------- Process elevation angle measurements
      PRINT *, '    elevation'

      N_DATA = 0
      DO I = INDEX1 , INDEX2
         IF (HMFLAG(I).EQ.1.) THEN
            N_DATA              = N_DATA + 1
            WKARRAY1(N_DATA)    = ELMEAS(I)
         END IF
      END DO

      IF (N_DATA.LT.3) THEN
         PRINT *, 'Error. N_DATA = ', N_DATA
         STOP
      END IF

      CALL LSQ_POLY2( P_COEF, TWORK, WKARRAY1, N_DATA)

      DO I = INDEX1 , INDEX2+NEXTRA
         IF (HMFLAG(I).NE.1.) THEN
            ELWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               ELWORK(I) = ELWORK(I) * TIMNOM(I) + P_COEF(J)
```

```
            END DO
         ELSE
            ELWORK(I) = ELMEAS(I)
         END IF
      END DO

      IF (ISEGMENT.EQ.NSEGMENT) THEN
         DO I = NWEIGH+1 , NAPEX+NEXTRA
            ELWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               ELWORK(I) = ELWORK(I) * TIMNOM(I) + P_COEF(J)
            END DO
         END DO
      END IF

C---------- Process azimuth angle measurements
      PRINT *, '    azimuth'

      N_DATA = 0
      DO I = INDEX1 , INDEX2
         IF (HMFLAG(I).EQ.1.) THEN
            N_DATA              = N_DATA + 1
            WKARRAY1(N_DATA)    = AZMEAS(I)
         END IF
      END DO

      IF (N_DATA.LT.3) THEN
         PRINT *, 'Error. N_DATA = ', N_DATA
         STOP
      END IF

      CALL LSQ_POLY2( P_COEF, TWORK, WKARRAY1, N_DATA)

      DO I = INDEX1 , INDEX2+NEXTRA
         IF (HMFLAG(I).NE.1.) THEN
            AZWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               AZWORK(I) = AZWORK(I) * TIMNOM(I) + P_COEF(J)
            END DO
         ELSE
            AZWORK(I) = AZMEAS(I)
         END IF
      END DO

      IF (ISEGMENT.EQ.NSEGMENT) THEN
         DO I = NWEIGH+1 , NAPEX+NEXTRA
            AZWORK(I) = P_COEF(1)
            DO J = 2 , P1E
               AZWORK(I) = AZWORK(I) * TIMNOM(I) + P_COEF(J)
            END DO
         END DO
      END IF
```

```
      END DO ! ISEGMENT

C-----------------------------------------------------------------------
C------ Smoothing range data by integrating range rate
C-----------------------------------------------------------------------
 300      PRINT *, 'Smooth range ? 1=integ rr, 2=average' , RNGOPTION
      READ(5,*) RNGOPTION

      IF (RNGOPTION.EQ.1) THEN
         RGWORK(1) = RGMEAS(1)
         RRWORK(1) = RRMEAS(1)
         DO I = 2 , NWEIGH+NEXTRA
            IF (HMFLAG(I).NE.1.) RRMEAS(I) = RRWORK(I)
            RGWORK(I) = RGWORK(I-1) + 0.5*CINT*(RRMEAS(I)+RRMEAS(I-1))
         END DO
      ELSE IF (RNGOPTION.EQ.2) THEN
         CONTINUE
      ELSE
         GO TO 300
      END IF

C-----------------------------------------------------------------------
C------ Smoothing data with moving average technique
C-----------------------------------------------------------------------

      PRINT 250, (AV WEIGHTS(I),I=1,N_AV_WEIGHT)
      PRINT *, ' TAR> Change weights ? (1:yes, 0:no) : '
          READ(5,*) I
      IF (I.NE.1) GO TO 290
      PRINT *, ' TAR> Number of weights ? :', N_AV_WEIGHT
      READ(5,*) I
      IF (I.LE.0) GO TO 290
      N AV WEIGHT = I
      PRINT *, ' TAR> Enter weights :'
      PRINT 250, (AV WEIGHTS(I),I=1,N_AV_WEIGHT)
 250      FORMAT(7X, 10(1X,F5.2), 9(7,7X,10(1X,F5.2)) )
      READ(5,*) AV WEIGHTS
 290      CONTINUE

      NPOINTS = NAPEX + NEXTRA

      IF (RNGOPTION.EQ.2) THEN
         CALL MOV_AVERAGE( WKARRAY1, RGWORK, NPOINTS
     ,                        AV_WEIGHTS, N_AV_WEIGHT)
         DO I = 1 , NPOINTS
            RGWORK(I) = WKARRAY1(I)
         END DO
      END IF
```

```
C CALL MOV_AVERAGE( WKARRAY1, RRWORK, NPOINTS
                           AV_WEIGHTS, N_AV_WEIGHT)
C
C DO I = 1 , NPOINTS
C   RRWORK(I) = WKARRAY1(I)
C END DO
  CALL MOV_AVERAGE( WKARRAY1, ELWORK, NPOINTS
                           AV_WEIGHTS, N_AV_WEIGHT)

  DO I = 1 , NPOINTS
    ELWORK(I) = WKARRAY1(I)
  END DO

  CALL MOV_AVERAGE( WKARRAY1, AZWORK, NPOINTS
                           AV_WEIGHTS, N_AV_WEIGHT)

  DO I = 1 , NPOINTS
    AZWORK(I) = WKARRAY1(I)
  END DO

C------------------------------------------------------------------------
C------ Keep data at T=0
C------ Make range, range rate, elevation vary linearly for the first secon
C------ (CINT=0.1)
C------------------------------------------------------------------------

  RGWORK(1) = RGMEAS(1)
  RRWORK(1) = RRMEAS(1)
  ELWORK(1) = ELMEAS(1)
  AZWORK(1) = AZMEAS(1)

  DO I = 2 , 10
    IF (RNGOPTION.EQ.2)
              RGWORK(I) = RGWORK(I-1) + 0.5*CINT*(RRWORK(I)+RRWORK(I-1))
C   RRWORK(I) = RRWORK(1) + (RRWORK(11)-RRWORK(1))*0.1*(I-1)
    ELWORK(I) = ELWORK(1) + (ELWORK(11)-ELWORK(1))*0.1*(I-1)
  END DO

C------------------------------------------------------------------------
C------ Plot processed measurements
C------------------------------------------------------------------------

  DO I = NAPEX+NEXTRA+1 , COUNT-1
    RGWORK(I) = RGMEAS(I)
    RRWORK(I) = RRMEAS(I)
    ELWORK(I) = ELMEAS(I)
    AZWORK(I) = AZMEAS(I)
  END DO

  DO I = 1 , COUNT-1
    CALL SAVEDATA( RGWORK(I), DATLEN, I, 101)
```

```
      CALL SAVEDATA( RRWORK(I), DATLEN, I, 102)
      CALL SAVEDATA( ELWORK(I)*DTORAD, DATLEN, I, 103)
      CALL SAVEDATA( AZWORK(I)*DTORAD, DATLEN, I, 104)
   END DO

   CALL PLOTROUTINE

C-----------------------------------------------------------------------
C------ Re-run approximation or replace measurements by approximation
C-----------------------------------------------------------------------

C------ Ask if user wants to modify the number of segments

   IF (DBFLAG.EQ.1.) THEN
      PRINT 500
500         FORMAT(1X, 'Modify number of time segments ? (1:yes, 0:no)')
      READ(5,*) I
      IF (I.EQ.1) GO TO 100
   END IF

C------ Replace real measurements by approximation

   DO I = 2 , NAPEX+NEXTRA
      RGMEAS(I) = RGWORK(I)
      RRMEAS(I) = RRWORK(I)
      ELMEAS(I) = ELWORK(I)
      AZMEAS(I) = AZWORK(I)
   END DO

   RETURN
   END
C***********************************************************************


C***********************************************************************
C
   SUBROUTINE LIMIT_WIND( WIND, ALT, NPOINTS, MAX_SLOPE)
C
C  This routine limits the variation of the wind to MAX_SLOPE.
C
C  For i=2,NPOINTS, the output WIND verifies:
C
C  abs[ (WIND(i)-WIND(i-1)) / (ALT(i)-ALT(i-1)) ] =< MAX_SLOPE
C
C***********************************************************************

   IMPLICIT NONE

   INTEGER NPOINTS
```

```
REAL WIND(NPOINTS), ALT(NPOINTS), MAX_SLOPE

INTEGER I
REAL DELTA, MAX_DELTA

DO I = 2 , NPOINTS

   MAX_DELTA = MAX_SLOPE * ABS( ALT(I)-ALT(I-1) )
   DELTA     = WIND(I) - WIND(I-1)

   IF ( ABS(DELTA).GT.MAX_DELTA ) THEN
      WIND(I) = WIND(I-1) + SIGN(MAX_DELTA,DELTA)
   END IF

END DO

RETURN
END
C*****************************************************************************
```

WHAT IS CLAIMED IS:

1. A trajectory analysis radar system comprising:

a radar antenna disposed proximate a gun barrel to track a projectile fired from the barrel along an actual trajectory of motion;

a radar transmitter coupled to communicate a sequence of radar signal pulses to the antenna after the projectile is fired from the gun barrel and at least until the projectile reaches a zenith in the trajectory of motion;

a radar receiver coupled to receive from the antenna radar signals reflected from the projectile and generate signals indicative of the position and velocity of the projectile;

a signal processor coupled to receive the position and velocity indicative signals from the radar receiver and generate position and velocity data for each of a plurality of different points along the trajectory of motion of the projectile; and

a data processor coupled to receive the position and velocity information from the signal processor and using the received information to update atmospheric tables for use in a subsequent firing.

2. A trajectory analysis radar system according to claim 1 wherein the radar receiver is a Doppler effect type of receiver.

3. A trajectory analysis radar system comprising:

a radar antenna disposed proximate a gun barrel to track a projectile fired from the barrel along an actual trajectory of motion;

a radar transmitter coupled to communicate a sequence of radar signal pulses to the antenna after the projectile is fired from the gun barrel and at least until the projectile reaches a zenith in the trajectory of motion;

a radar receiver coupled to receive from the antenna radar signals reflected from the projectile and generate signals indicative of the position and velocity of the projectile;

a signal processor coupled to receive the position and velocity indicative signals from the radar receiver and generate position and velocity data for each of a plurality of different points along the trajectory of motion of the projectile; and

a data processor coupled to receive the position and velocity information from the signal processor and using the received information to update atmospheric tables for use in a subsequent firing, the data processor assuming a current atmospheric model and repeatedly calculating a derived trajectory using the current analytical model, deriving error values representing differences between the actual trajectory and the derived trajectory, and using the error values to correct the current atmospheric model to cause the current atmospheric model to converge toward an accurate representation of atmospheric conditions down range of the antenna.

4. A trajectory analysis radar system according to claim 1 wherein the entire radar system is mounted on a weapon firing the projective.

5. A trajectory analysis radar system for analyzing a trajectory of a projectile fired from a gun at a firing position, the system comprising:

a radar system having an antenna mounted on the gun, the radar system tracking at least a portion of the trajectory of the projectile and generating information representing the tracked trajectory portion;

a signal processing system receiving the trajectory representing information generated by the radar system and converting said information to numeric coordinate data representing the trajectory of the projectile; and

a data processing system coupled to receive the numeric coordinate data from the signal processing system and generate in response thereto an atmospheric model accurately representing atmospheric conditions through which the trajectory of the projectile passes.

6. A mobile weapon comprising:

a gun firing a projectile through a trajectory;

a radar system mounted on the weapon and generating radar data representing the actual trajectory of the projectile;

a signal processing system mounted on the weapon, the signal processing system receiving the radar data and converting the radar data to coordinate based numeric data representing the trajectory of the projectile; and

a fire control data processor mounted on the weapon and receiving the coordinate based numeric data from the signal processing system, the fire control data processor analyzing the coordinate based numeric data to generate in response thereto an atmospheric model representing atmospheric conditions along the trajectory of the projectile.

7. A mobile weapon comprising:

a gun firing a projectile through a trajectory;

a radar system mounted on the weapon and generating radar data representing the actual trajectory of the projectile;

a signal processing system mounted on the weapon, the signal processing system receiving the radar data and converting the radar data to coordinate based numeric data representing the trajectory of the projectile; and

a fire control data processor mounted on the weapon and receiving the coordinate based numeric data from the signal processing system, the fire control data processor analyzing the coordinate based numeric data to generate in response thereto an atmospheric model representing atmospheric conditions along the trajectory of the projectile, the fire control data processor including means for establishing a current set of atmospheric parameters and then repeatedly generating a derived trajectory, determining error differences between the actual trajectory and the derived trajectory, and using the error differences to update the current set of atmospheric parameters until the current set of atmospheric parameters converges to a model that accurately represents actual atmospheric conditions.

8. A mobile weapon according to claim 7 wherein the establishing means uses a down range component of projectile position and velocity error to generate a correction value for a down range component of wind velocity, uses a cross range component of projectile position and velocity error to generate a correction value for a cross range component of wind velocity and uses an elevation component of position and velocity error to generate a correction value for air density.

9. A mobile weapon according to claim 8 wherein said atmospheric model represents components of down range and cross range wind and air density at a plurality of different elevation levels separated by no more than 1000 foot elevation intervals.

10. A method of deriving a true atmospheric model using an actual projectile trajectory comprising the steps of:

establishing a current atmospheric model;

deriving a trajectory of the projectile based upon the current atmospheric model;

determining error differences between the actual projectile trajectory and the derived trajectory; and

correcting the current atmospheric model in response to the determined error differences so as to tend to reduce the error differences between a derived trajectory based upon the current atmospheric model and the actual projectile trajectory.

11. A method of deriving a true atmospheric model according to claim 10 further comprising the step of repeating the steps of deriving, determining and correcting until the current atmospheric model represents actual atmospheric conditions with a desired accuracy.

12. A method of deriving a true atmospheric model according to claim 11 wherein the steps of deriving, determining and correcting are repeated exactly once.

13. A method of deriving a true atmospheric model according to claim 10 wherein the atmospheric model represents down range and cross range wind velocity and air density at elevation intervals no greater than 1000 feet.

14. A method of firing a gun of a weapon system comprising the steps of:

firing an initial round of a projectile;

tracking the initial round with a radar system mounted on the weapon system to determine an actual trajectory of the initial round;

determining in response to the actual trajectory an atmospheric model representing atmospheric conditions in the vicinity of the weapon system;

aiming a gun of the weapon system in response to the determined atmospheric model; and

firing at least one round from the gun that is aimed in response to the determined atmospheric model.

15. A method of firing according to claim 14 wherein the determining step further includes the steps of:

establishing a current atmospheric model;

calculating a projectile trajectory using the atmospheric model;

determining error differences between the actual trajectory and the calculated trajectory; and

correcting the current atmospheric model in response to the error differences to tend to cause the current atmospheric model to more accurately represent actual atmospheric conditions encountered by the initial round of a projectile.

16. A mobile weapon comprising:

a gun firing a projectile through a trajectory;

a radar system mounted on the weapon and generating radar data representing the actual trajectory of the projectile;

a signal processing system mounted on the weapon, the signal processing system receiving the radar data and converting the radar data to coordinate based numeric data representing the trajectory of the projectile; and

a fire control data processor mounted on the weapon and receiving the coordinate based numeric data from the signal processing system, the fire control data processor analyzing the coordinate based numeric data to generate in response thereto an atmospheric model representing atmospheric conditions along the trajectory of the projectile, the fire control data processor establishing a current set of atmospheric parameters and then repeatedly generating a derived trajectory in response to the current set of atmospheric parameters, determining error differences between the actual trajectory and the derived trajectory, and using the error differences to update the current set of atmospheric parameters until the current set of atmospheric parameters converges to a model that accurately represents actual atmospheric conditions.

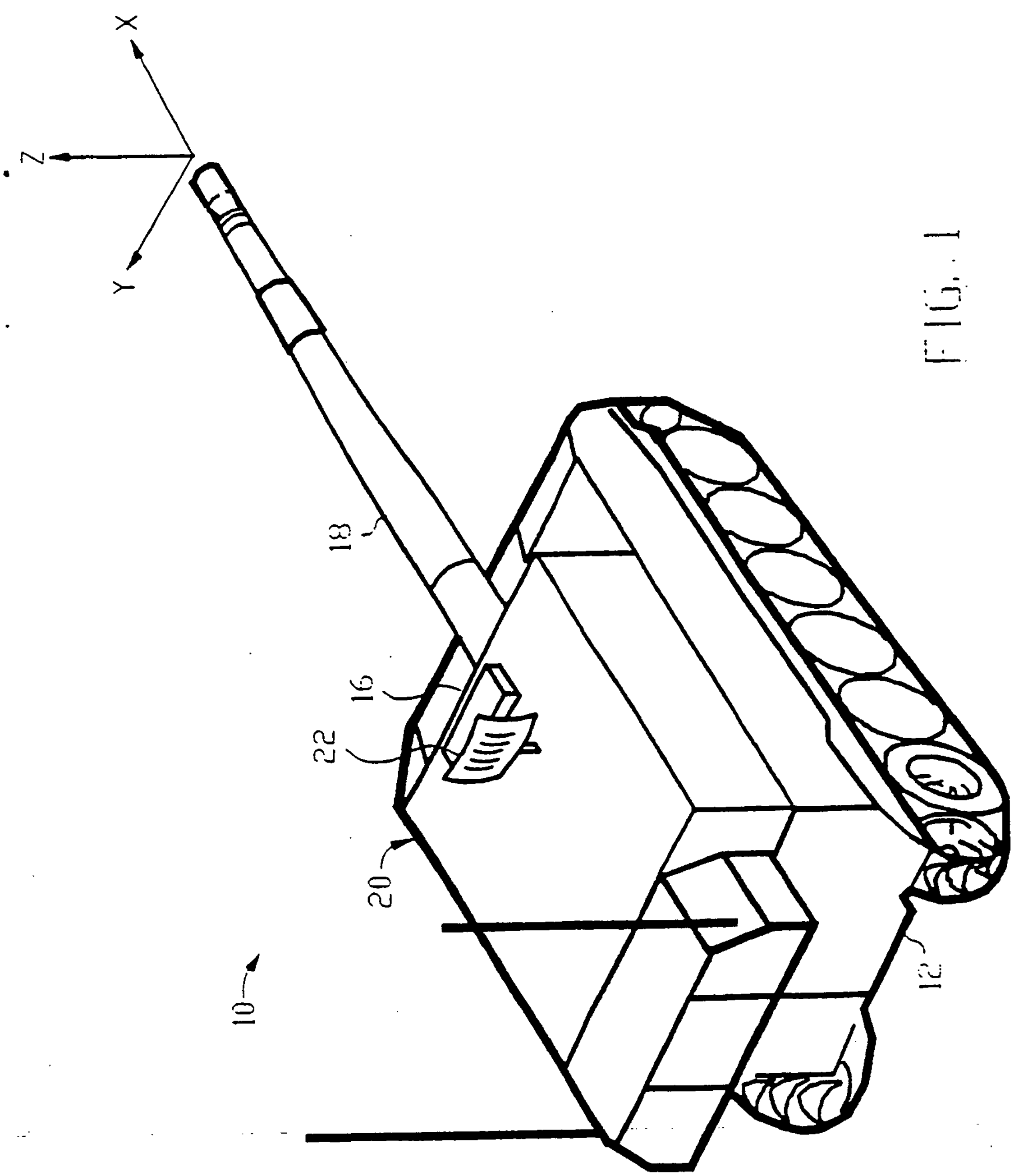

FIG. 1

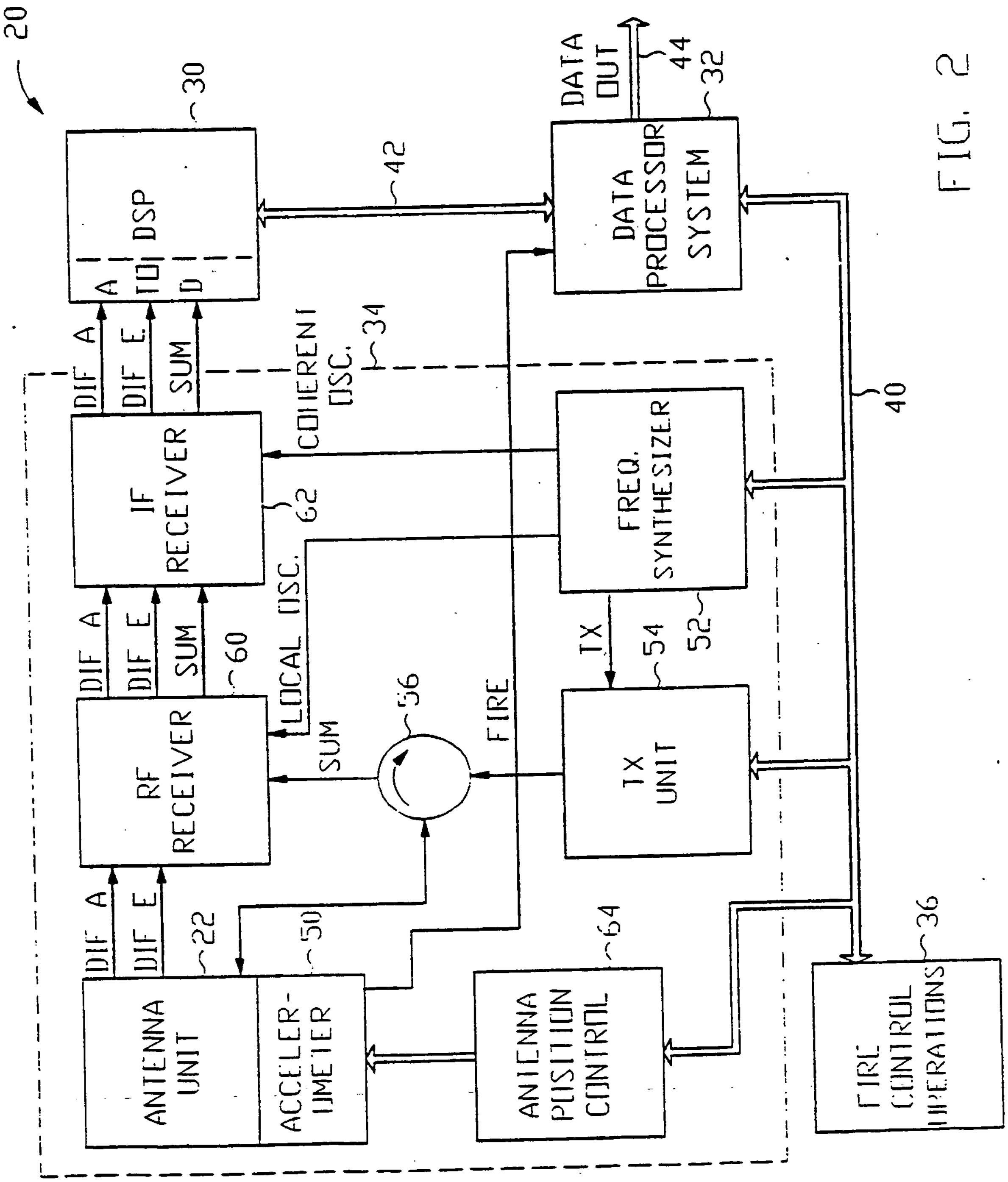
20
DSP
A TO D
30
42
DATA OUT
44
32
DATA PROCESSOR SYSTEM
DIF A
DIF E
SUM
COHERENT OSC.
34
IF RECEIVER
62
FREQ. SYNTHESIZER
40
LOCAL OSC.
60
RF RECEIVER
SUM
56
FIRE
TX
54
52
TX UNIT
22
50
ANTENNA UNIT
ACCELER-OMETER
64
ANTENNA POSITION CONTROL
36
FIRE CONTROL OPERATIONS

FIG. 2

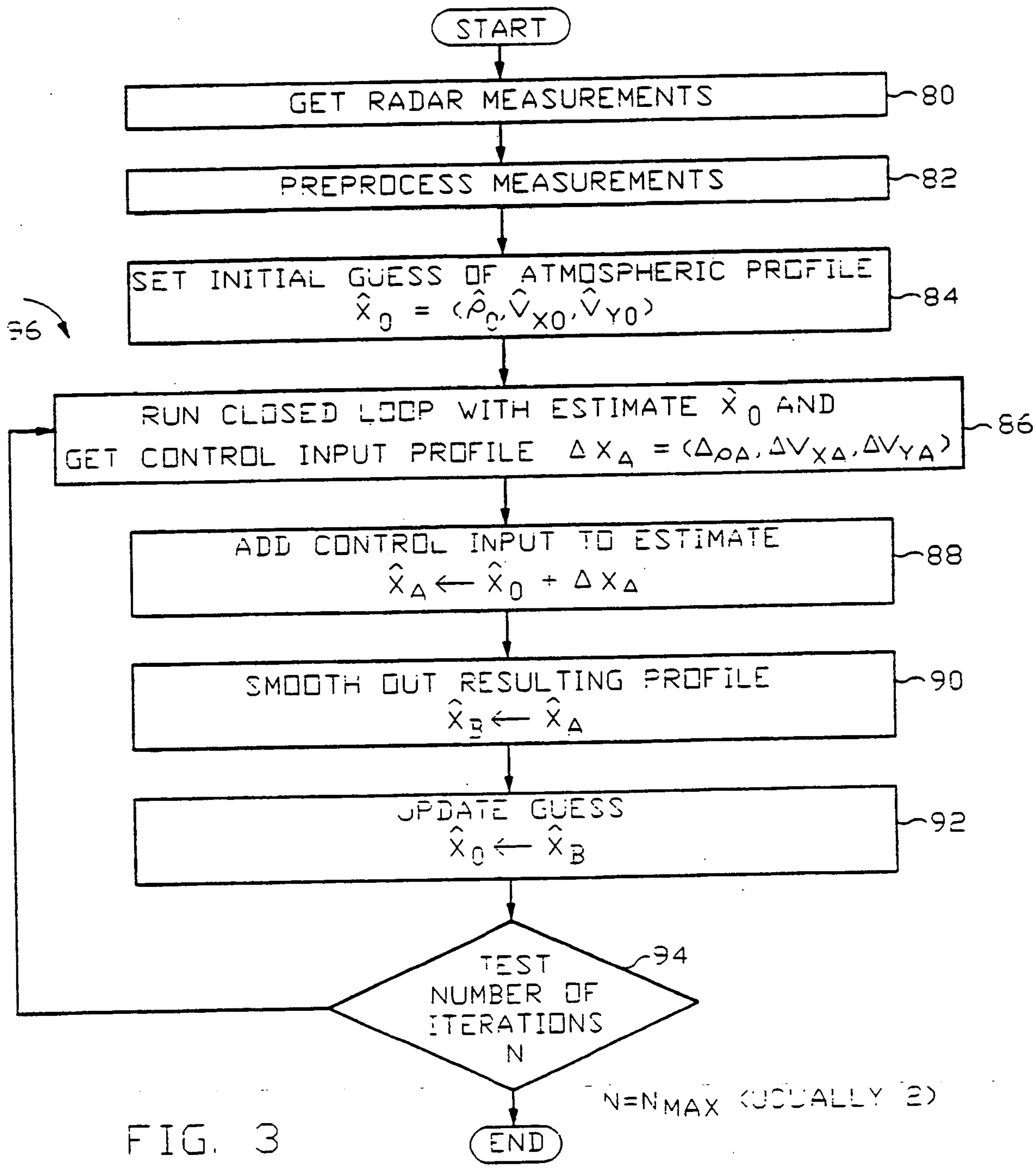
START
GET RADAR MEASUREMENTS
80
PREPROCESS MEASUREMENTS
82
SET INITIAL GUESS OF ATMOSPHERIC PROFILE
$\hat{X}_0 = (\hat{\rho}_0, \hat{V}_{X0}, \hat{V}_{Y0})$
84
96
RUN CLOSED LOOP WITH ESTIMATE $\hat{X}_0$ AND
GET CONTROL INPUT PROFILE $\Delta X_\Delta = (\Delta_{\rho\Delta}, \Delta V_{X\Delta}, \Delta V_{Y\Delta})$
86
ADD CONTROL INPUT TO ESTIMATE
$\hat{X}_\Delta \leftarrow \hat{X}_0 + \Delta X_\Delta$
88
SMOOTH OUT RESULTING PROFILE
$\hat{X}_B \leftarrow \hat{X}_\Delta$
90
UPDATE GUESS
$\hat{X}_0 \leftarrow \hat{X}_B$
92
TEST NUMBER OF ITERATIONS N
94
$N=N_{MAX}$ (USUALLY 2)
END

FIG. 3

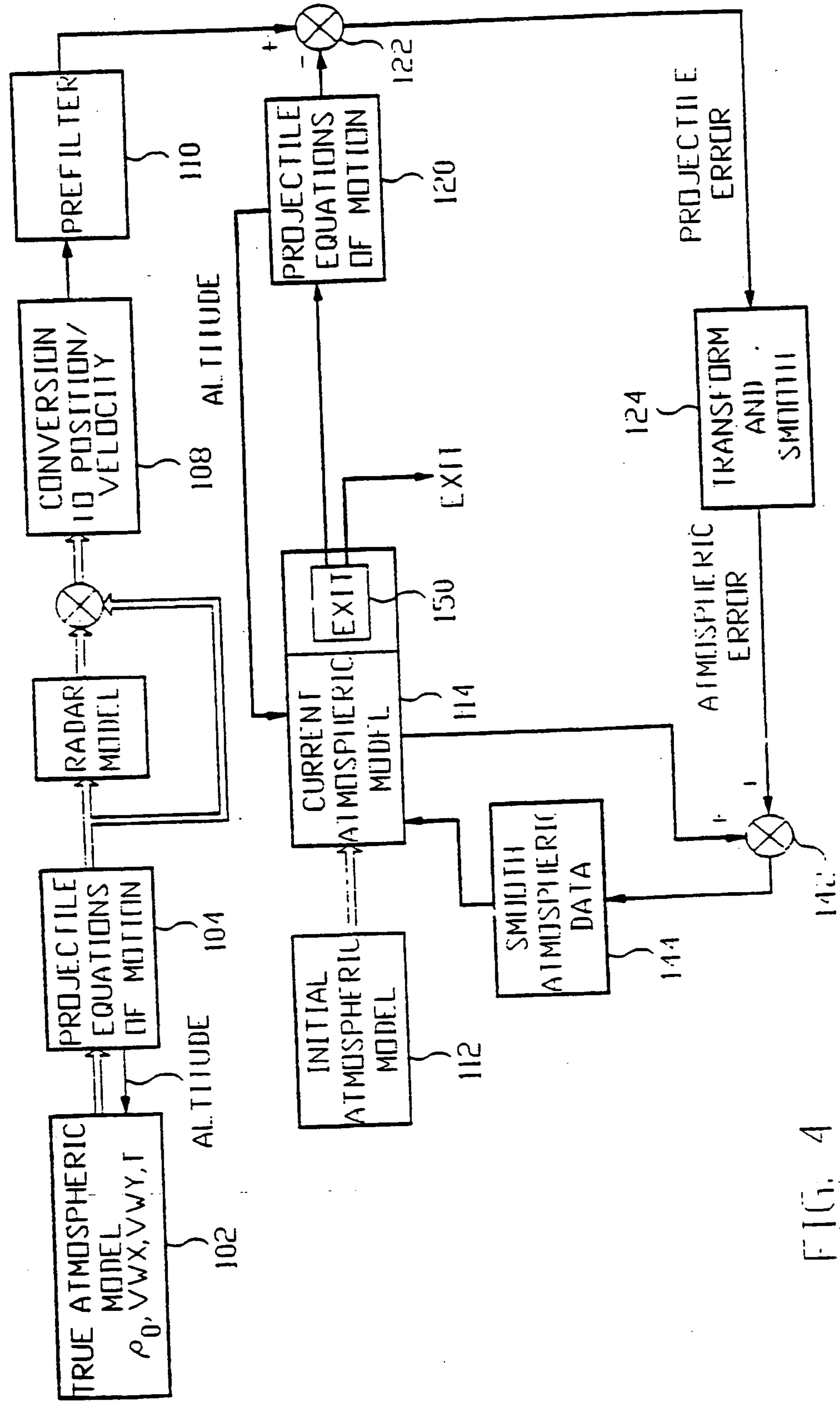
TRUE ATMOSPHERIC MODEL ρ_0, VWX, VWY, T
102
ALTITUDE
PROJECTILE EQUATIONS OF MOTION
104
RADAR MODEL
CONVERSION TO POSITION/ VELOCITY
108
PREFILTER
110
ALTITUDE
INITIAL ATMOSPHERIC MODEL
112
CURRENT ATMOSPHERIC MODEL
114
EXIT
150
EXIT
PROJECTILE EQUATIONS OF MOTION
120
+
-
122
PROJECTILE ERROR
TRANSFORM AND SMOOTH
124
ATMOSPHERIC ERROR
SMOOTH ATMOSPHERIC DATA
144
142

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/03377

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :F41G 7/00; G06G 7/80
US Cl :342/67; 235/417; 364/423; 89/41.07

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 235/400

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 3,758,052 (MCALEXANDER ET AL) 11 September 1973, Whole document.	1,2,4,5,6,14
Y	US, A, 3,748,440 (ALEXANER) 24 July 1973, Whole document.	1,2,4,5,6, 10, 11,12,13,14
A	US, A, 4,655,411 (FRANZEN ET AL) 07 April 1987, Whole document.	1-16
A	US, A, 4,128,837 (PAGE) 05 December 1978, Whole document.	1-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

21 JULY 1992

Date of mailing of the international search report

12 AUG 1992

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